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AN EVALUATION OF THE WESTERN PHOSPHATE INDUSTRY AND ITS RESOURCES

(In Five Parts)

4. Wyoming and Utah

By J. S. Coffman and A. L. Service

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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Walter R Hibbard Jr
Director

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PREFACE

This is the fourth in a series of five reports describing Bureau of Mines investigations of the Western phosphate resources and industry. The five-year program has included field examination of practically all known phosphate deposits in Montana, Idaho, Wyoming, and Utah; classification and estimation of possible resources available by surface mining; potential resources above and within 100 feet below entry level; studies of mining, beneficiation, and processing methods; and utilization of Western phosphate rock and marketable products.

Parts 1, 2, and 3 of this series, "Introductory Review," "Montana," and "Idaho" have been published as Reports of Investigations 6485, 6611, and 6801, respectively. Part 5, "Trends and Outlook" will be published as Report of Investigations 6935.

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AN EVALUATION OF THE WESTERN PHOSPHATE INDUSTRY AND ITS RESOURCES

(In Five Parts)

4. Wyoming and Utah

by

J. S. Coffman[1] and A. L. Service[1]

ABSTRACT

Wyoming is estimated to have more than 700 million tons and Utah more than 2.5 billion tons of +10 percent P_2O_5 phosphate rock considered to have some future economic potential. In Wyoming, the +24 and +18 percent P_2O_5 rock potential resources total nearly 250 and 450 million tons, respectively. In Utah, the +31, +24, and +18 percent rock total approximately 33 million, 222 million, and 2.2 billion tons, respectively. These resources are all located above the local drainage levels and do not include latent resources.

All of the mining and beneficiation of phosphate rock in the two States is done by San Francisco Chemical Co. The facilities include open pit mines at Vernal, Utah, and Leefe, Wyo.; an underground mine in the Crawford Mountains, Utah, and beneficiation plants at Leefe and Vernal. One of the principal markets for the phosphate rock is Western Phosphates, Inc., fertilizer plant at Garfield, Utah. Recent exploration and development has been undertaken by different companies in the Southeastern Wind River Range, Sublette Range, and Crawford Mountains. The facilities at Leefe and Vernal are in the process of expansion.

Some of the areas of western Wyoming contain vast quantities of phosphate rock in minable units, but, because of their remote location, are classed as latent areas. In these areas, there are estimated to be about 700 million, 2 billion, and 3 billion tons of phosphate rock in the +24, +18, and +10 percent P_2O_5 grade classes, respectively. The Snake River Range of Idaho and Wyoming is also estimated to contain roughly 21, 106, 177, and 214 million tons of potential resources in the +31, +24, +18, and +10 grade categories, respectively. This area also contains a large amount of latent rock in the more remote areas.

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The possibility of exploitation of the undeveloped deposits of Wyoming and Utah depends on market conditions. In view of the vast, untapped open pit resources available, particularly in Idaho and Utah, and the rapid expansion of all facilities in the Western phosphate field, it appears that it will be some time before market conditions warrant opening any but the best of the Wyoming or Utah deposits.

INTRODUCTION

The phosphate deposits occur in the main mountain masses of western Wyoming, and in northeastern Utah as a continuation of the Western phosphate field in Idaho and Montana. The deposits in the western part of the area are within the influence of the western Wyoming folded belt and are generally highly folded and faulted. The eastern part of the area is affected only by simple uplift, and the phosphate beds are gently tilted.

The first phosphate development in the Western field was in Utah and Wyoming; however, emphasis soon shifted to nearby deposits in Idaho which were richer in grade and more adaptable to mining. Presently, there are three operating mines and two beneficiation plants in the two States. All mining and beneficiation is done by San Francisco Chemical Co.; Western Fertilizer Co. at Garfield, east of Salt Lake City, is one of the major consumers of Wyoming and Utah phosphate rock and concentrate. Large tonnages are shipped to northern Idaho and British Columbia, Canada.

A considerable amount of exploration is underway in the more promising phosphate areas in the two States, but most of the undeveloped deposits have not yet been of interest because of the low grade and inaccessibility. In fact, many of the deposits, particularly in Wyoming, are so remote with respect to rail transportation and access, that, in this study, they have been classified as latent--not commercially available in the foreseeable future.

The principal function of this work is to estimate total phosphate rock resources above drainage entry level in Wyoming and Utah, and to evaluate the economic potential of the various areas.

ACKNOWLEDGMENTS

The author is indebted to several companies and individuals for their cooperation and help during the course of this investigation. San Francisco Chemical Co. personnel at Montpelier, Idaho, and Vernal, Utah, in particular, contributed a great amount of material and time to further the project. Others whose aid should be acknowledged include:

Kern County (Calif.) Land Development Co.;
Susquehanna Western Inc.;
Western Fertilizers, Inc.;
FMC Corp.;
Union Pacific Railroad;
Gas Hills Uranium Co.;

A. J. Eardley, Dean, College of Mines and Geology, University of Utah; and Pacific Power and Light Co.

The following Federal and State agencies contributed much information:

Bonneville Power Administration;
Geological Survey (Conservation Branch), Salt Lake City;
Bureau of Land Management;
Wyoming State Land Board; and
Utah State Land Commision.

HISTORY

The existence of phosphate rock deposits in the Western States became generally known during the early 1900's. The original discovery has been credited to Albert Richter, Salt Lake City, who recognized occurrences near La Plata, Cache County, Utah, in 1889 (31),[2] traced these occurrences north to Bear Lake, and subsequently tried, without success, to interest middle western fertilizer producers. In 1904, C. C. Jones examined phosphate deposits in the vicinity of Woodruff Creek and later traced outcrops into southeastern Idaho, western Wyoming, and northeastern Utah. The first development and mining followed shortly after Jones started his work, and he has been credited as the pioneer of the development of the Western phosphate field (35, pp. 292-293).

The first withdrawals of phosphate lands came in 1908; before that time all phosphate deposits were located as placer claims according to interpretations of existing mining laws. The Bradley claims in the Crawford Mountains, Utah, were later patented as lode claims and, immediately, many of the old placer claims were relocated as lode claims by persons other than the original locators. This led to litigation and court claims that continued until the U.S. Department of the Interior decided a case, in Utah, in favor of the lode claimant. Lode mining law then applied to all phosphate claims until the Federal leasing law went into effect in February 1920. Since that time the Federal Government has retained title to all phosphate lands on public domain and has the right to lease them according to the specifications of the Federal leasing law of 1920, as amended (51).

The Geological Survey is evaluating withdrawn phosphate lands for the purpose of classification. A total of 302,099 acres presently classified as phosphate land in the Western field are distributed as follows:

Montana	3,833
Idaho	[1] 270,036
Wyoming	25,293
Utah	2,937

[1] Includes State lands.

[2] Underlined numbers in parentheses refer to items in the list of references.

At the time of discovery and shortly thereafter, the most accessible phosphate resources were in the Crawford Mountains area in Utah and the Sublette Range in Wyoming, and these were among the first to be actively developed (table 1). Later, the more extensive deposits in the central part of the field were discovered and emphasis shifted to the Montpeller, Paris, and Soda Springs areas in Idaho. Late in 1906, the Union Phosphate Co., Cokeville, Wyo. (later the Cokeville Phosphate Co.) started to develop a phosphate deposit about 1-1/2 miles east of Cokeville. The first production was reported in 1907, and by 1910 about 6,000 tons of phosphate rock was reported to have been shipped. This mine operated intermittently until 1931, and a total of 25,000 long tons of rock was reported to have been produced by 1925. The same company made an unsuccessful attempt to develop an underground mine in the Beckwith Hills area at about the same time and produced a small amount of ore from an open cut in some flat-lying beds in the area.

The United States Phosphate Co., Salt Lake City, Utah, started to develop an underground mine in York Canyon in the Sublette Range area in 1913. Pulverized phosphate rock was shipped by rail to Salt Lake City and was distributed for direct application to the soil. The product sold under a guarantee of +32 percent P_2O_5. Production was discontinued in 1917, and no further work has been reported (35, p. 291).

In 1907, the first production of about 12,000 tons was reported from the Arickaree mine in the Crawford Mountain area. This activity continued on a limited basis until 1920, and no further activity was reported until 1953, when San Francisco Chemical Co. started development of the Arickaree, Pawnee, and Mandan mines; work on the Tuscarora and Emma mines was started in 1954. In 1964 the only operation in the Crawford Mountains area was the Cherokee mine, developed in 1955, which has maintained a production of 375,000 to 400,000 tons per year. The Arickaree mine was closed in 1958, and the other mines were closed a few years earlier. Descriptions of the mines and mining methods are presented in a Bureau of Mines publication (62).

The first major production from the Beckwith Hills area was in 1947 when San Francisco Chemical Co. started development of the Leefe surface mine near Sage Junction, Wyo. In 1958 production was about 139,000 tons of phosphate rock, and by 1960 production potential had reached its peak. Construction of plant facilities at Leefe started in 1956, and in 1965 the complex included primary and secondary crushing units, flotation circuits, pulverizing units, and two fluosolids reactors for calcining. A planned expansion program includes the addition of another fluosolids reactor and other equipment to increase production. Capacity of the plant in 1964 was about 450,000 to 500,000 tons of concentrate and calcined rock per year. The product is shipped to fertilizer and phosphoric acid producers in the United States and Canada. Feed for the plant comes from the Cherokee underground mine and the Leefe open pit.

TABLE 1. - Phosphate rock production in the Western field 1925-64 (long tons)[1]

Year	Wyoming[2]	Utah[2]	Idaho[3]	Montana[3]
1925	6,697	-	65,934	-
1926	4,464	-	33,113	-
1927	6,250	-	45,260	-
1928	3,388	-	37,477	-
1929	2,679	-	35,899	40
1930	1,339	-	59,932	6,005
1931	1,000	-	60,978	67,893
1932-40	-	-	512,000	203,562
1941	-	1,340	97,274	105,108
1942	-	1,184	114,079	150,402
1943	-	-	108,916	119,764
1944	-	-	112,565	186,434
1945	-	-	123,340	150,858
1946	-	Small	[4]312,658	179,994
1947	51,845	-	[4]845,045	236,229
1948	138,946	Small	[4]434,375	248,683
1949	([5])	-	[6]471,305	355,169
1950	172,500	-	[7]573,044	210,165
1951	195,332	580	[4]695,026	[6]304,507
1952	168,816	-	[4]620,551	[6]332,299
1953	143,000	26,024	1,070,773	[7]658,000
1954	153,279	70,939	[6]878,920	[7]734,000
1955	94,487	179,825	1,122,012	[7]799,000
1956	119,230	124,773	1,206,526	[6]557,000
1957	18,000	114,000	1,418,000	[6]534,000
1958	139,341	98,000	1,393,000	[6]825,000
1959	184,074	189,860	1,590,000	[6]940,000
1960	130,000	203,149	1,973,000	[6]1,051,000
1961	97,391	600,000	1,687,000	[7]1,085,000
1962	117,848	675,000	1,744,000	[7]1,113,000
1963	163,609	725,000	1,739,000	[8]1,240,000
1964	180,154	825,000	1,964,000	[8]1,302,000

[1] (9, 59, 67).
[2] Mine production.
[3] Sold or used.
[4] Includes Utah (sold or used).
[5] Not available.
[6] Includes Wyoming (sold or used).
[7] Includes Wyoming and Utah (sold or used).
[8] Includes Wyoming, Utah, and Arkansas (sold or used).

Another phosphate mining operation was started in 1947 on Commissary Ridge, about 7 miles north of Kemmerer, Wyo. This was known as the South Mountain mine operated by Phosphate Mines, Inc., a locally organized group. The operation consisted of an open pit near the crest of the ridge and an adit farther down the hill that intersected the phosphate bed underground.

This mine operated intermittently for a few years and sold a small amount of rock for direct application to the soil.

Several other companies, as well as individual prospectors, have shown much interest in Wyoming and Utah phosphate deposits. The most recent activity is the exploration program started in 1964 by FMC Corp. near Brazer Canyon in the Crawford Mountains area. Table 2 lists mining companies that have been active in Wyoming and Utah.

TABLE 2. - Past and presently active phosphate mining companies in Wyoming and Utah

Company	Mine	Location
Wyoming (Lincoln County)		
San Francisco Chemical Co......	Leefe[1].........	Leefe.
Union Phosphate Co.............	Cokeville......	Cokeville.
Cokeville Phosphate Co.........	......do.......	Do.
United States Phosphate Co.....	York Canyon....	Sublette Range.
Kemmerer Mines, Inc. (Phosphate Mines, Inc.).	South Mountain.	Kemmerer.
Utah		
San Francisco Chemical Co......	Cherokee[1]......	Crawford Mts., Rich County.
	Arickaree......	Do.
	Mandan.........	Do.
	Emma...........	Do.
	Tuscarora......	Do.
	Pawnee.........	Do.
	Woodruff Canyon	Woodruff Creek, Rich County.
	Vernal[1]........	Vernal, Uinta County.
American Agricultural Chemical Co. (Bradley Bros.).	Bradley........	Crawford Mts., Rich County.
	Sioux..........	Do.
J. R. Simplot Co...............	Rex Peak.......	Do.
Garfield Chemical And Manufacturing Co. and John M. U'ren.	Little Diamond Creek.	Little Diamond Creek, Utah County.
United States Phosphate Co.....	Crawford Group.	Crawford Mts., Rich County.
Humphreys Phosphate Co.........	Humphreys Group	Vernal, Uinta County.
F. T. Pearl Minerals Co........	Pearl..........	South Crawford Mts., Rich County.

[1]Presently active.

Aside from the Leefe concentrating plant, Wyoming has no other phosphate processing plants. Several small plants in the State produce basic plant foods, bulk blended materials, and other fertilizer products. The largest basic phosphate fertilizer processing plant in Utah is Western Fertilizers, Inc., in Garfield. Most of the other producers are located in agricultural areas and supply bulk blended materials, liquid fertilizers, and other types of plant nutrients.

San Francisco Chemical Co. began building plant and mine facilities at the Humphreys Phosphate Co. property about 12 miles north of Vernal, Utah, in 1960. The 500-ton-per-day capacity mine and flotation plant went on line in 1961. All production from this plant goes to the Western Fertilizers, Inc., fertilizer complex at Garfield.

About 1,000 feet of exploratory drifting was done in Raymond Canyon in the Sublette Range by Kern County, Calif., Land Co. in 1961. Several sections were crosscut for grade determinations and, at last report, work was being done to determine a processing technique for the ore. At about the same time, Gas Hills Uranium Co., Casper, Wyo., staked about 90 vanadium claims near Afton; the company has since applied for phosphate prospecting permits covering outcrops in the area of the claims.

Phosphate land acquisition is continuing in the more remote areas of Wyoming and Utah; however, the majority are on marginal and submarginal land. A recent and significant acquisition of prospecting permits in a relatively good phosphate area southwest of Lander, Wyo., was made by Susquehenna Western Co., Riverton, Wyo. The company is doing exploration work on their leases and prospecting permits. Also, they are investigating the costs of converting their Riverton uranium plant to a wet-process fertilizer plant.

RESOURCES AND INDUSTRY TRENDS

A number of previous surveys have provided information on phosphate resources in the two States. In general, the resource evaluation depended upon the particular type of rock of commercial interest in the locality. In the Crawford Mountain and Beckwith Hills areas, total resources were estimated at 90 million and 2.8 million long tons, respectively (20, pp. 513, 522). Both estimates were based on 5-foot beds of +70 percent BPL (+32 percent P_2O_5) rock. The Crawford Mountains estimate took into account a mining depth of 2,000 feet.

Another example of a type of resource calculation occurs when a more closely controlled survey has been made in a restricted area. In this case, the lateral cutoff points are established for the purpose of a specific survey and do not consider the possible ore that may continue beyond the boundaries with no significant change in characteristics. This is illustrated in a Bureau of Mines study in the Lander, Wyo., area where two rectangular blocks of ore were drilled. Reserves were computed for both underground mining methods and for various stripping depths. This study was made to determine the practical mining potential of what was considered to be a commercial quantity of ore.

Another example of restricted type of resource study is the recent reporting of an area east of Ogden, Utah, where resources of more than 45 million short tons of +18 percent and more than 28 million short tons of +24 percent P_2O_5 rock have been estimated in a one square mile area (47, p. 6). The purpose of the restriction of the area in this case is undoubtedly for the purpose of establishing quantitative figures for this "discovery" type of survey.

A more recent report deals with the phosphate resources of western Wyoming and lists figures for reserves above entry level, from entry level to 1,000 feet below, and from 1,000 feet to 5,000 feet below entry level (52, p. 155).

In the previously mentioned resource estimates (20, pp. 503, 506, 513, 522, 526) the adjacent areas of southwestern Wyoming and northeastern Idaho were included. The calculations assumed a 5-foot high-grade bed and a 2,000-foot mining depth, with the exception of the flat-lying Beckwith Hills deposit and the Laketown deposit, where a 6-foot bed was used. The results are as follows:

	Million long tons
Sublette anticline (34,000-foot strike length):	
North (both limbs)............................	5.4
South (east limb).............................	27.0
Cokeville (3,000-foot strike length).............	2.4
Beckwith Hills (flat lying)......................	2.8
Crawford Mountains (113,000-foot strike length)..	90.0
Laketown area (7,000-foot strike length).........	6.75

The Crawford Mountains and the Laketown area were included in a more recent study in which the Crawford Mountains resources were revised to 60 million tons, using more critical bed area calculations (64, pp. 7-8). The same study includes data on the entire State, with the resource estimates as shown in table 3.

TABLE 3. - Phosphate rock resources in Utah, 1943[1]

Area	P_2O_5, percent	Bed thickness, feet	Tonnage, long tons
Vernal Field....................	+18	19.0	1,100,000,000
	+20	4.7	7,430,000
	+22	5.0	400,000,000
North Flank Uinta:			
East.........................	+22	2.8	109,000,000
West.........................	+22	2.8	10,000,000
Wasatch Range:			
Laketown.....................	+32	6.0	6,750,000
North of Midway..............	+27	3.6	8,000,000
Little Diamond Creek.........	+25	5.0	1,300,000
Crawford Mountains..............	+32	3-5	60,000,000

[1] (64, pp. 21-22).

In the Lander area, Wyo., the phosphate resources were computed over a strike length of approximately 15 miles and included bed areas above and 100 feet below drainage level entry points (table 4).

TABLE 4. - Summary of phosphate rock resources in the Lander are, Wyoming, 1947[1]

	Grade, percent P_2O_5	Short tons	Bed area, acres	Bed thickness, feet	Long tons per 100 feet below entry level
Upper bed.	+18	46,600,000	2,695	3'7-6'0	6,600,000
	+10	101,175,000	5,451	3'7-6'4	13,825,000
Lower bed.	+24	16,000,000	1,237	3'6	1,510,000
	+18	29,890,000	2,296	3'6+	3,780,000

[1] (28, pp. 79-80).

A later survey by the Bureau of Mines in the Lander area determined proven ore reserves on two small blocks. One of these blocks, called the Macfie area, is on the southern end of the study area, and the other block, called the Twin Creek area, is on Twin Creek, about 5 miles to the south. Both estimates are calculated on the lower or Meade Peak member, and results based on +22 percent P_2O_5 rock are summarized as follows:

Area	Location	Short tons
Macfie.........	Underground..............	2,581,000
Twin Creek.....	............do............	3,898,100
	75-foot stripping depth...	3,397,500

In the Ashley Creek-Brush Creek area, in the southeastern Uinta Range, comparatively large resources of phosphate rock occur in the approximate grade range of 16 to 20 percent P_2O_5. Previous estimates in this area consider various levels of overburden and extend to 1,000 feet below drainage level. Total resources to drainage level have been estimated at 1.8 billion short tons (30, p. 172).

The most recent published resource estimate (table 5) includes part of western and central Wyoming and part of Idaho (52, pp. 153-155). The method of calculation used drainage levels as a basis for dividing above entry level and the below entry level rock in place.

Bureau of Mines studies indicate potential resources of phosphate rock in Wyoming and Utah, estimated on the basis of in-place rock above drainage level on exposed outcrops and in beds extending more than 3 feet in thickness (table 6). The largest percentage of the immediately available potential occurs in Utah, mainly because of the supply of beneficiation-grade rock in the Vernal area. Most of the resources in Wyoming must be classed as latent, being both submarginal in grade and remote from processing facilities, rail transportation, and market outlets. In all probability, these latent resources will not be developed unless there is a presently unforeseeable local need. Establishment of other industries requiring rail transportation, power, etc. would conceivably lead to development of some of the more promising deposits. Railroad facilities in areas such as Vernal and the Salt River Range in Wyoming, would enhance these deposits and probably promote additional development.

TABLE 5. - Phosphate rock resources in western Wyoming and part of southeastern Idaho, 1963[1] (million short tons)

Mountain range	+31 percent P_2O_5			+24 percent P_2O_5			+18 percent P_2O_5		
	Above entry level	Entry level to 1,000 feet below	1,000 to 5,000 feet below	Above entry level	Entry level to 1,000 feet below	1,000 to 5,000 feet below	Above entry level	Entry level to 1,000 feet below	1,000 to 5,000 feet below
Gros Ventre...	205.7	108.8	591.6	333.1	327.1	1,424.8	909.1	628.7	2,391.7
Wind River....	-	-	-	-	-	-	463.7	589.3	2,164.2
Teton.........	7.6	-	-	20.0	8.0	-	31.8	15.7	-
Big Hole......	-	-	-	63.0	32.1	-	120.3	59.1	-
Snake River...	-	-	-	84.5	50.4	48.0	467.3	131.1	29.6
Caribou.......	68.1	88.1	272.3	180.8	190.9	595.6	508.1	481.8	1,512.0
Hoback........	-	-	-	288.6	69.1	-	1,052.6	252.2	-
Wyoming.......	-	-	-	646.2	391.0	785.6	1,913.4	1,470.7	4,184.6

[1] (52, p. 155).

TABLE 6. - Phosphate rock resources of Wyoming, Utah, and Snake River Range of Idaho[1] (million short tons)

Phosphate districts	+31 percent P_2O_5		+24 percent P_2O_5		+18 percent P_2O_5		+10 percent P_2O_5	
	Above drainage level entry	First 100 feet below entry	Above drainage level entry	First 100 feet below entry	Above drainage level entry	First 100 feet below entry	Above drainage level entry	First 100 feet below entry
Idaho:								
Snake River Range:								
Big Hole Mountains............	-	-	47.4	5.8	86.1	10.8	95.8	11.8
Northeastern..................	-	-	-	-	18.5	3.2	31.2	5.3
Northwestern..................	20.8	2.7	58.7	7.5	72.0	9.3	87.9	11.4
Total Snake River Range......	20.8	2.7	106.1	13.3	176.6	23.3	214.9	28.5
Wyoming:								
Salt River Range:								
Strawberry Creek-Willow Creek.	-	-	58.8	3.0	89.3	4.9	172.8	8.3
Swift Creek-Cottonwood Creek..	-	-	166.0	10.1	188.9	12.1	214.8	14.4
Total Salt River Range.......	-	-	224.8	13.1	278.2	17.0	387.6	22.7
Total Sublette Range............	-	-	26.4	5.8	41.7	7.9	146.8	27.5
Wind River Range:								
North of Red Creek-Twin Creek Divide......................	-	-	-	-	98.8	14.6	143.5	21.9
Twin Creek-Tweed Creek.........	-	-	-	-	20.3	7.4	20.3	7.4
Tweed Creek-Beaver Creek......	-	-	-	-	15.3	1.7	15.3	1.7
Beaver Creek-Sweetwater River.	-	-	-	-	25.0	4.6	25.0	4.6
Total Wind River Range.......	-	-	-	-	159.4	28.3	204.1	35.6
Total Wyoming................	-	-	247.9	18.2	479.3	53.2	738.5	85.8
Utah:								
Uinta Range:								
Vernal Field..................	-	-	-	-	1,825.0	65.5	1,825.0	65.5
Flaming Gorge.................	-	-	83.9	3.2	107.0	4.4	389.7	16.0
Western.......................	-	-	-	-	203.5	-	448.0	-
Total Uinta Range............	-	-	83.9	3.2	2,135.5	69.9	2,214.7	81.5
Wasatch Range:								
Little Diamond Creek[2].........	-	-	5.0	0.4	5.0	0.4	5.0	0.4
Dry Bread Hollow..............	-	-	10.6	1.5	13.4	1.9	18.1	2.6
Woodruff Creek[2]...............	-	1.9	-	3.7	-	3.7	-	3.7
Laketown......................	-	0.6	-	1.9	-	3.5	-	4.8
Total Wasatch Range..........	-	2.4	15.6	6.7	18.4	8.1	23.2	12.1
Total Crawford Mountains.....	32.7	5.8	122.3	22.0	217.1	38.1	340.5	79.2

[1] Latent resources are not included.
[2] Grade information is available only on selected beds.

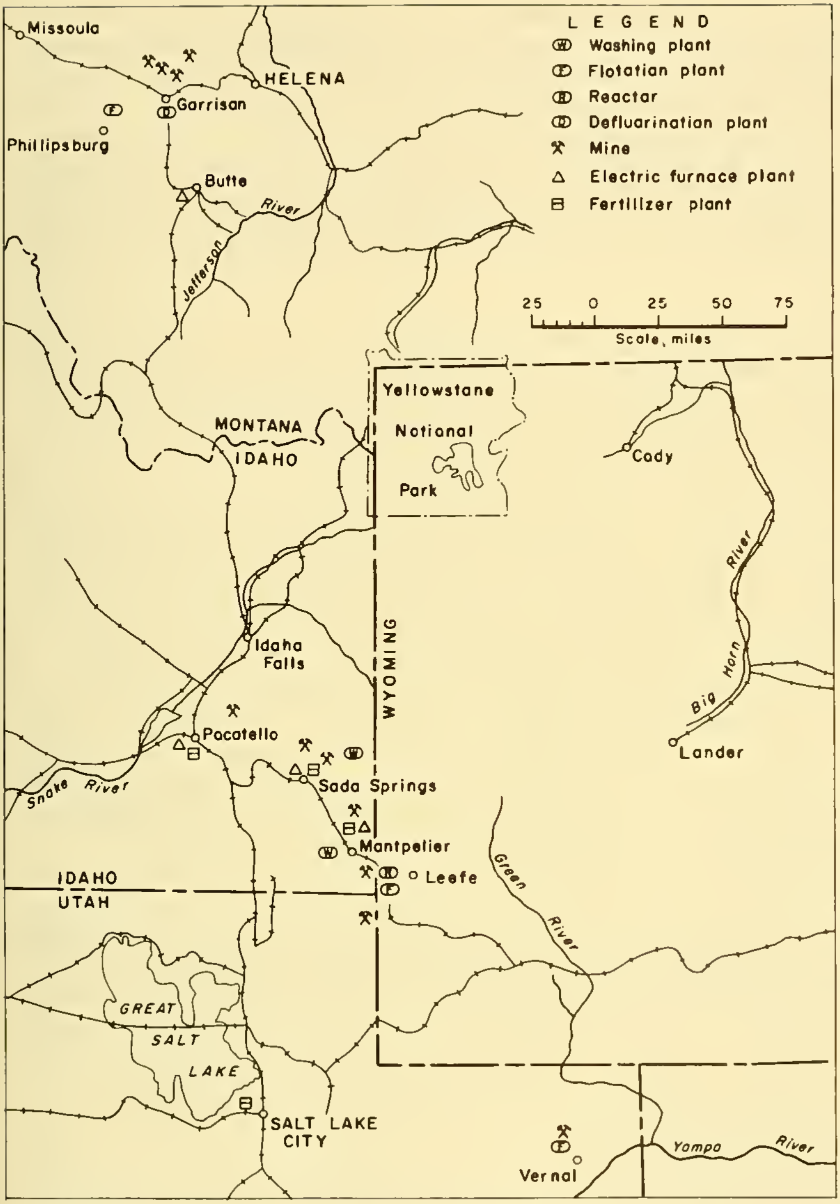

FIGURE 1. - Mining and Processing Facilities in the Western Phosphate Field.

All crude ore produced from mines in Wyoming and Utah is concentrated, pulverized, or calcined and marketed for use in fertilizer plants. San Francisco Chemical Co. is the only operating company in both States, although FMC Corp. is conducting an exploration program in the Crawford Mountains area. Several other companies are actively exploring phosphate deposits in western Wyoming and northeastern Utah.

The Western phosphate industry is expanding steadily, with the main centers of mining and processing being located in Idaho and Montana (fig. 1). If this expansion continues as expected, activity will extend to Wyoming and Utah where large areas of unleased phosphate lands are available. Phosphate producers are mining and beneficiating ores for use in processing plants many miles from the source.

The outlook for further expansion of the industry in Wyoming and Utah is not as optimistic as it is for Idaho and Montana. The availability of lower cost power from Flaming Gorge Dam may influence elemental phosphorus producers in their selection of a site for an electric furnace complex at some future date. The majority of the resources in both States are low in P_2O_5 content in comparison with the Idaho field. Most of the mine run ore needs to be upgraded before it can be used, and this is a costly operation requiring expensive equipment. At the present time, the capital investment of an integrated mine and fertilizer complex is too great when the limited marketing areas are considered.

In Wyoming there are three areas that could possibly contain enough reserves to warrant constructing processing facilities. These are the southeastern Wind River Range, the Sublette Range, and the Salt River Range. The Sublette Range contains about 23 million tons of +24 percent P_2O_5 ore, with about 7 million tons of this in the 5- to 9-foot upper bed averaging between 28 and 30 percent P_2O_5. In the southeastern Wind River Range area, the Bureau of Mines blocked out more than 8 million tons of +22 percent P_2O_5 ore in an 8-foot bed; approximately 50 percent of this is available by stripping to a maximum depth of 75 feet. The Salt River Range contains about 225 million tons of resources above entry level (+24 percent P_2O_5 rock) in the more accessible northern part.

All of these resource figures represent in-place phosphate rock available under ideal conditions. Even with generous mining loss estimates each of the areas could support a processing facility for several years. The problems and economics of development depend upon a properly oriented exploration program, adequate planning for the processing facilities, and a firm market for the product.

The Sublette area contains sizable reserves of +28 percent rock with a carbon and fluorine content of about 10 percent. An acid-grade product could be produced by calcination, defluorination, and desliming. The rock in the southeastern Wind River Range would have to undergo a more rigorous beneficiation treatment, but it is near a source of sulfur for manufacturing sulfuric acid. Both areas are conveniently located to the railroad (10 to 20 miles over good roads). The Salt River Range has relatively large quantities of +24 percent P_2O_5 rock; however, it is about 40 miles over a high pass from the nearest railhead.

In Utah the areas for probably future development are the southern part of the Crawford Mountains and the fringes of the Vernal field. Exploration is presently underway on a group of patented claims in the Crawford Mountains by FMC Corp., operators of the largest electric furnace complex in the West.

The Western fringes of the Vernal phosphate area contain large resources of 16 to 20 percent P_2O_5 rock, ample to support processing facilities. At the present time, however, the lack of railroad transportation inhibits exploitation of any but the best occurrences in this area. The nearest railhead is at Craig, Colo., a distance of 130 miles. The possibility of extending this line into Vernal has been investigated but, according to local reports, no conclusions have been reached. In any case, a railroad from either Craig or Salt Lake City would most certainly advance development of the Vernal phosphate area.

In addition to these larger areas, there are several small, widely scattered districts where relatively minor amounts of +31 percent P_2O_5 rock occur. These areas each represent resources of 100,000 to 500,000 tons of ore available by open pit methods. It is possible, however, that almost any of these areas could be mined for a small amount of acid-grade rock, provided an outlet could be obtained.

DEVELOPMENT AND MINING

The overall picture of the phosphate deposits in Wyoming and Utah is one of extremes in both mining and development. To start with there are deposits that have been worked for many years, such as Leefe and the Crawford Mountains, and then there are comparatively great areas of phosphate occurrences that are presently marginal or submarginal when considering present-day phosphate economics.

In Idaho large reserves of phosphate rock are amenable to open pit mining; this means there is a relatively thick section of minable ores. In the Wyoming part of the field, in particular, the phosphate section is much thinner, the grade of minable beds is lower, and the size of individual deposits (in available tonnages) is smaller. This would, in the event of development, change the approach from a large, long-term, integrated phosphate-rock-consuming enterprise to a smaller phosphate-rock-supplying operation. Many of the Wyoming deposits are more adaptable to smaller operations and the market for the product would be the fertilizer processing industry. Considering economic conditions, the crude ore would have to be used directly, necessitating either ideal rock characteristics or a beneficiation operation.

The future Wyoming phosphate producer is faced with the prospect of adapting smaller, lower grade, and more remote deposits to the present market conditions and demands. Most of the phosphate rock can be mined, but the majority of the occurrences are more amenable to underground methods. The section is thin, topography is rugged, and dips of the beds are generally very steep, particularly in western Wyoming. Mining conditions apparently are generally good. No serious problems of support, dilution, or crushed beds were noted in the underground workings on vertical strata in the Sublette Range. Similarly, the rock conditions in flat-lying deposits in the Lander area have been found to be favorable to underground mining.

The outlook for Utah is somewhat different than for Wyoming; the phosphate in Utah lies mainly in areas that are either presently operating or under development, or in areas that probably would not be exploited at any time in the foreseeable future. There are, of course, phosphate occurrences on the fringes of currently operating properties and on some unleased lands that may be developed as market conditions demand.

In addition to the operating properties in Utah and their fringe areas, the phosphate area east of Ogden contains a comparatively thick section of minable phosphate. While the outcrop area was mapped in an early survey (7), the grade of the phosphatic section was not known until the Geological Survey trenched and sampled the outcrop in 1963 (47). Undoubtedly, a great deal of interest will be shown in this area since it is near a railroad (Ogden) and close to processing facilities at Salt Lake City.

Currently operating mines in Utah are in two widely different areas of environment. The Cherokee mine, operated by the San Francisco Chemical Co., is an underground mine in the highly folded and faulted Crawford syncline in the Crawford Mountains. The soft nature of these rocks promote problems of roof support, ore dilution, etc., although the highly carbonaceous ore can be easily upgraded to acid-grade by crushing, desliming, and calcining. On the other extreme, the same company's mine in the Vernal area is more of a quarrying operation on a flat-lying, well-delineated ± 20-foot phosphatic zone. The ore must be upgraded from about 16 to 22 percent P_2O_5 to acid-grade (+31 percent P_2O_5) and requires crushing and grinding, classifying, and flotation; the process is rigidly controlled to comply with changing rock characteristics.

Most of the higher potential phosphate areas in Wyoming and Utah are controlled by individuals and companies holding Federal and State phosphate leases, phosphate prospecting permits, and patented claims (tables 7, 8, and 9). The claims were located during the early years of discovery before the Federal program of phosphate land withdrawals began in 1908.

TABLE 7. - Federal phosphate leases and prospecting permits in Wyoming

	Number	Date	Acres	Township	Range	Description	Phosphate district	Owner
Leases................	W-0225913	12-1-62	320	31 N	99 W	Sec 8: SE¼ 9: W½SW¼ 17: E½NE¼	SE Wind River......	Susquehanna Western Inc.
	W-0225914	12-1-62	360	30 N	99 W	Sec 11: N½NW¼, SE¼NW¼, W½NE¼, W½SE¼, SE¼SE¼ 12: SW¼SW¼	........do.........	Do.
	W-0280560	5-1-64	188.75	26 N		Sec 18: lots 1,4[1] 6: lot 5[1] 31: W½SE¼, NW¼NE¼[1]	Sublette Range.....	Kern County (Calif.) Land Co.
	W-03467	11-7-62	756.81	21 N	120 W	Sec 1: lot 8[1] 2: lots 5,7,9,11, S½NE¼[1] 10: SE¼[1] 15: W½NE¼, E½NW¼, W½SE¼, E½SW¼[1]	Beckwith Hills.....	Stauffer Chemical Co.
	-	-	-	22 N	120 W	Sec 35: lots 24,25[1] 36: lots 9,10[1]		
Total lease acreage	-	-	1,625.56	-	-	-	-	-
Permits................	W-0128024	3-1-62	1,520	30 N	98 W	Sec 28: N½SW¼, SE¼SW¼, S½SE¼, SW¼SE¼ 29: S½NE¼, NW¼, N½SW¼, SE¼SE¼, SE¼ 30: NE¼, NE¼SE¼ 32: NE¼NE¼ 33: N½ 34: NW¼	SE Wind River Range	Susquehanna Western Inc.
				30 N	99 W	Sec 24: NE¼SE¼		
	W-0161153	11-1-62	2,007.83	31 N	99 W	Sec 34: SE¼NE¼, E½SE¼ 35: W½NW¼, SW¼	........do.........	Do.
				30 N	99 W	Sec 2: lots 2,4, SW¼NE¼, S½NW¼, SW¼, W½SE¼ 3: lots 1,2, SE¼NE¼, NE¼SE¼ 13: NW¼NW¼, S½NW¼, SW¼ 14: NW¼NE¼, S½NE¼, NW¼, N½SW¼, N½SE¼, SE¼SE¼ 23: E½NE¼ 24: NW¼		
	W-0161152	11-1-62	2,015.72	31 N	99 W	Sec 7: all 8: SE¼NE¼, W½NE¼, E½NW¼, SW¼NW¼, N½SW¼, SE¼SW¼ 17: SW¼NE¼, W½, NW¼SE¼ 18: SE¼NE¼, SE¼	........do.........	Do.
				31 N	100 W	Sec 1: SE¼SE¼ 12: E½NE¼, SE¼ 13: N½NE¼, NE¼NW¼		
	W-0161108	2-1-63	960.10	22 N	118 W	Sec 4: lots 6,7, SE¼NW¼, SE¼SW¼, SW¼SE¼ 9: W½E½ 17: E½NE¼	Tump Range........	John A. Teichert.
				23 N	118 W	Sec 21: NW¼NE¼, E½W½ 28: E½W½ 33: E½NW¼, SE¼SW¼, SW¼SW¼		
	W-0157358	2-1-63	480	22 N	118 W	Sec 9: E½W½ 21: SW¼NW¼, SW¼, E½NW¼, NE¼SW¼		
Total prospecting permit acreage.	-	-	6,983.65	-	-	-	-	-

[1]Excludes area covered by claims.

TABLE 8. - Federal phosphate leases and prospecting permits in Utah

	Number	Acres	Township	Range	Description	Phosphate district	Owner
Leases	U-06929	111.52	11 N	8E	Sec 5: lots 15,17,20,22,23	Crawford Mountains....	Mountain Fuel Supply Co.
	U-092104	1,370.16	9 N 10 N	7E 7E	Sec 1: lots 3,6,9, SE¼NW¼ Sec 13: W½SE¼, E½SW¼, SW¼SW¼ 14: lot 15 23: lots 1-6, NE¼, N½SE¼ 24: NW¼, W½NE¼, E½SW¼ 25: W½	..........do..........	John D. Archer
	U-016242	1,815.13	2 N	19 E	Sec 10: lots 1-4, S½N½, S½ 11: lots 1-4, S½N½, N½SW¼, SE¼SW¼, SW¼ 12: all 13: E½NE¼, NE¼SE¼	Flaming Gorge.........	Trans-Southern Corp.
	U-016377	2,549.24	3 N 3 N	20 E 21 E	Sec 36: lot 6, E½E½ Sec 30: lots 3-11, S½NE¼ 31: lots 1-9, S½NE¼, SE¼ 32: lots 1,2, S½N½, S½ 33: W½SW¼ 34: all	..........do..........	Petroleum Properties, Inc.
	U-017558	2,509.48	2 N	20 E	Sec 7: lots 1-7, N½NE¼, E½NW¼, S½SE¼ 8: all 9: all 10: lots 1-3, NE¼NE¼, SW¼, S½N½, N½SE¼ 11: lots 6,9	..........do..........	Yuba Consolidated Industries, Inc.
	U-026255	1,806.88	2 N	20 E	Sec 15: S½NW¼ 16: S½N½, S½ 17: S½N½, S½ 18: lots 1-4, E½W½, E½ 20: N½N½	..........do..........	Do.
	U-032111	233.54	2 N	18 E	Sec 2: lots 5-8, S½S½	..........do..........	Glen E. Bryan, Jr.
	U-015354	207	1 S	6 E	Sec 14: lot 4, S½SE¼ 23: lot 1, N½NE¼	Western Uinta.........	R. W. Woolstenhulme.
	SL-051785- U-030044	840	8 S	4 E	Sec 11: SW¼SW¼ 14: W½SW¼, NW¼ 15: E½, SE¼ 22: E½ 23: W½W½	Southern Wasatch Range	John M. U'ren.
Total Utah lease acreage	-	11,482.95	-	-	-	-	-
Permits	U-098788	1,476.73	3 S	20 E	Sec 7: lot 1, SW¼NE¼, E½NE¼, SE¼NW¼, N½SE¼, SE¼SE¼ 8: E½, E½W½, NW¼NW¼, W½SE¼ 9: N½, N½SW¼, NW¼SE¼ 10: W½NW¼, NW¼SW¼	Vernal Field..........	Elizabeth B. and J. D. Archer.
	U-0110886	1,349.38	3 S	20 E	Sec 3: W½SW¼ 4: lot 4, SW¼NW¼, S½ 5: lots 1-3, S½NE¼, N½S½, SE¼NW¼, SE¼SW¼, S½SE¼ 6: lots 4-6, SE¼NW¼, E½SW¼, W½SE¼, SE¼SE¼	..........do..........	John D. Archer.
	U-0110927	1,889	2 S	19 E	Sec 20: all 29: all 31: all	..........do..........	Elizabeth B. Archer.
	U-044176	693.25	1 S	7 E	Sec 4: all	Western Uinta.........	J. W. Gibbons and R. W. Woolstenhulme.
Total Utah permit acreage	-	5,408.36	-	-	-	-	-

TABLE 9. - State land phosphate leases in Wyoming and Utah

	Number	Acres	Township	Range	Description	Phosphate district	Owner
Wyoming.......	026482	200	30 N	99 W	Sec 13: $SE\frac{1}{4}$ 24: $NW\frac{1}{4}NE\frac{1}{4}$	SE Wind River Range	Susquehanna Western Inc.
	026501	400	30 N	98 W	Sec 19: $S\frac{1}{2}$, $SW\frac{1}{4}NW\frac{1}{4}$ 20: $SW\frac{1}{4}SW\frac{1}{4}$	........do.........	Do.
	026509	120	30 N	99 W	Sec 24: $S\frac{1}{2}$, $NE\frac{1}{4}$, $NE\frac{1}{4}NE\frac{1}{4}$	........do.........	Do.
	021902	80	30 N	99 W	Sec 11: $E\frac{1}{2}SW\frac{1}{4}$	........do.........	T. R. Marshall Jr.
	021941	640	23 N	116 W	Sec 16: all	South Ridges.......	Kemmerer Coal Co.
	026686	640	25 N	116 W	Sec 16: all	........do.........	J. C. Tertling Co.
	026689	640	24 N	116 W	Sec 16: all	........do.........	Do.
	026690	640	25 N	116 W	Sec 36: all	........do.........	Do.
	026681	760	22 N	118 W	Sec 8: $E\frac{1}{2}$, $S\frac{1}{2}$, $E\frac{1}{2}NE\frac{1}{4}$ 16: $SW\frac{1}{4}NE\frac{1}{4}$	Tump Range.........	Do.
	026682	320	22 N	118 W	Sec 8: $W\frac{1}{2}$	........do.........	Do.
	026683	320	23 N	118 W	Sec 32: $W\frac{1}{2}$	........do.........	Do.
	026684	320	22 N	118 W	Sec 5: lots 7,8, $S\frac{1}{2}NW\frac{1}{4}$, $SW\frac{1}{4}$	........do.........	Do.
	026685	240	22 N	118 W	Sec 5: lots 5,6, $W\frac{1}{2}SE\frac{1}{4}$, $S\frac{1}{2}NE\frac{1}{4}$	........do.........	Do.
	026687	640	25 N	118 W	Sec 36: all	........do.........	Do.
	026688	640	24 N	118 W	Sec 16: all	........do.........	Do.
	026691	640	23 N	116 W	Sec 16: all	........do.........	Do.
	026565	280	22 N	118 W	Sec 5: $E\frac{1}{2}SE\frac{1}{4}$, $NW\frac{1}{4}$ 16: $NW\frac{1}{4}NE\frac{1}{4}$	........do.........	J. A. Teichert.
Total Wyoming State leases	-	7,520	-	-	-	-	-

Utah..........	ML18420	200	10 N	7 E	Sec 36: S½NW¼, NE¼NW¼, N½SW¼	Crawford Mountains.	Mineral Fertilizer Co.
	ML4859	160	11 N	7 E	Sec 36: lots 10,11,13,14	........do.........	John D. Archer.
	ML4684	221.59	12 N	8 E	Sec 32: lots 11-21	........do.........	Do.
	ML4685	376.71	11 N	7 E	Sec 36: lots 4,9, 15-25	........do.........	Do.
	ML4609	79.89	10 N	7 E	Sec 1:[1] 11:[1] 12:[1]	........do.........	Do.
	ML19526	40	10 N	7 E	Sec 36: NW¼NW¼	........do.........	Do.
	ML19535	40	10 N	7 E	Sec 36: SW¼SW¼	........do.........	Do.
	ML20138	640	3 S	20 E	Sec 2: all	Vernal Field.......	Elizabeth B. Archer.
	ML20782	1,771.03	3 S	21 E	Sec 4: lots 6,7 5: lots 2,3, S½NE¼, SE¼NW¼, S½ 6: lots 6,7, SE¼, E½SW¼ 7: lots 1,2, NE¼, E½NW¼, N½SE¼, NE¼SW¼ 8: N½NE¼, SW¼NE¼, NW¼, N½, SW¼, SE¼SW¼	........do.........	Mountain Fuel Supply.
	ML20783	440	3 S	20 E	Sec 11: N½ 12: W½NW¼, SE¼NW¼	........do.........	Do
	ML16546	820.06	2 N	20 E	Sec 2: lots 1-3, NE¼SE¼, E½NE¼ 36: all	Flaming Gorge......	Yuba Consolidated Industries.
	ML22009	160	3 N	21 E	Sec 32: SW¼	........do.........	W. B. Martin.
	ML22010	160	2 N 3 N	18 E 17 E	Sec 2: S½N½ 36: S½S½	........do.........	Do.
	ML22011	761.20	3 N 2 N	19 E 17 E	Sec 32: NW¼SW¼, S½SW¼, S½SE¼ 2: lots 1-4, S½NE¼, S½	........do.........	Do.
	ML21553	920	3 S	4 E	Sec 12: W½ 13: NW¼, NW¼SW¼ 32: W½, W½SE¼	Central Wasatch Range.	W. J. Colman.
	ML22304	200	3 S	4 E	Sec 1: SW¼SE¼, SE¼SW¼ 12: W½SE¼ 13: NW¼NE¼		
	ML21503	562.92	7 N 8 N	3 E 3 E	Sec 2: lots 1-3, S½NE¼, SE¼, SE¼NW¼, E½SW¼ Sec 35: S½SE¼	Northern Wasatch Range.	Marien McGahey.
	ML21505	240.20	7 N 8 N	3 E 3 E	Sec 2: lot 4, SW¼NW¼, W½SW¼ Sec 35: N½SE¼	........do.........	J. C. Osmond.
	ML21502	960	8 N	3 E	Sec 34: all 35: N½	........do.........	David Arnold.
Total Utah State leases	-	8,753.60	-	-	-	-	-

[1]Four mining claims.

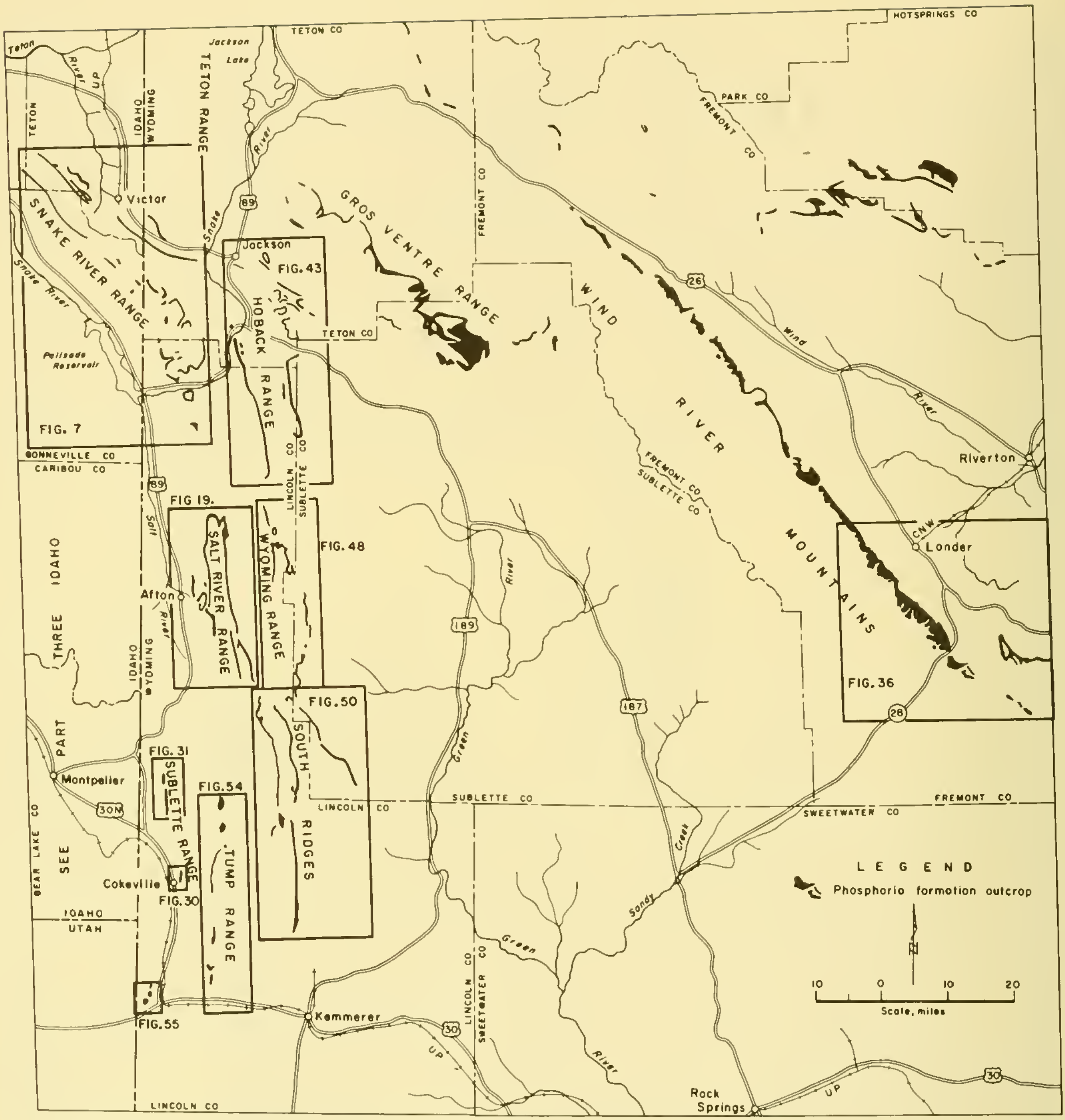

FIGURE 2. - Phosphate Deposits in Wyoming and the Snake River Range, Idaho.

WYOMING-UTAH PHOSPHATE DEPOSITS

Location and Distribution

Phosphate deposits described in this report occur in the main mountain masses of central and western Wyoming and northern Utah, and in an extension of the Snake River Range deposits in Idaho (figs. 2 and 3). The economic potential of phosphate deposits in this fringe area of the Western field

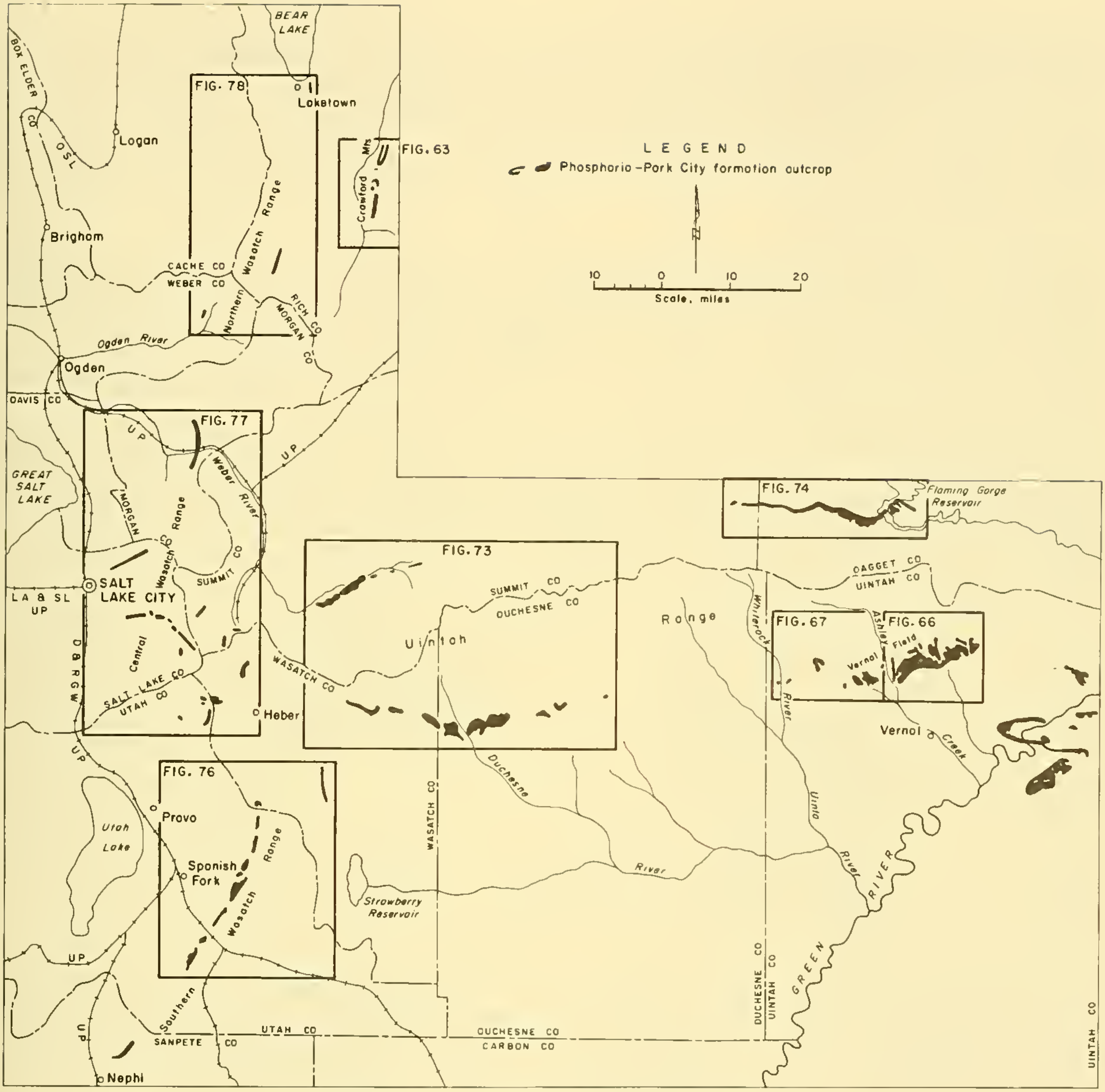

FIGURE 3. - Phosphate Deposits in Utah.

depends upon a number of factors, including percent P_2O_5 in the rock, bed thickness, extent of individual deposits, access, availability of rail transportation, potential market areas, and others.

The Phosphoria formation and its related units of the Park City formation and eastern Wyoming equivalents occur throughout most of Wyoming and Utah. In this study, however, certain arbitrary cutoffs have been made to limit the discussion to areas that could be developed, mined, or actively explored at some future date. For this purpose, the cutoff thickness of individual beds is 3 feet. Phosphate rock containing 10 to 18 percent P_2O_5 is considered economically potential only when it occurs with at least +3 feet of beneficiation-grade (+18 percent P_2O_5 rock). This differentiation is not applicable to Idaho, where 10 to 18 percent rock is practically always associated with greater thicknesses of higher grade material, or to Montana where these lower grades are not considered economically minable. However, in fringe areas of the Wyoming-Utah field, where the phosphate content eventually grades out to a mere trace, some form of arbitrary lower cutoff grade and thickness is necessary.

The above classification necessarily restricts this study to phosphate occurrences in certain localities in the main mountain ranges in Wyoming and Utah. Other areas that have been previously studied indicate the extent of the phosphatic interval. In these outlying areas the original surveys were generally made as part of the land classification and withdrawal program.

The Wyoming-Utah phosphate field covers a much larger area than the Idaho and Montana fields. Of the approximately 135,000 square miles in the Western phosphate field, nearly two-thirds is in Wyoming and Utah. The following phosphate districts (figs. 2 and 3) have been used to describe the phosphate deposits in this report:

Wyoming	Utah
Snake River Range	Crawford Mountains
Salt River Range	Uinta Range
Sublette Range	Wasatch Range
Wind River Range	
Latent areas:	
South Ridges	
Tump Range	
Hoback Range	
Wyoming Range	
Beckwith Hills	

In 1964 the Leefe open pit mine, Cherokee underground mine (Crawford Mountains district), and the Vernal open pit mine (Uinta district) were the only large producers in the two States. Other districts with small or limited production were the Sublette and Southern Wasatch districts, and the southern end of Commissary Ridge north of Kemmerer.

In most of the districts, limited access to the phosphate deposits is available by paved and gravel roads. Rail transportation is available in a few areas. Railway lines include the Union Pacific Railroad; The Denver and Rio Grande Railroad; Chicago and Northwestern Railway; and Chicago, Burlington, and Quincy Railroad (fig. 4).

In the areas that have the most phosphate potential nearby power facilities are adequate for processing (fig. 5). Practically all of the power for the central Wyoming phosphate area is supplied by Pacific Power and Light Co. Western Wyoming is served by both Idaho Power Co. and Utah Power and Light Co.; the latter serves nearly all of the phosphate areas in Utah.

FIGURE 4. - Transportation Facilities in the Northwest.

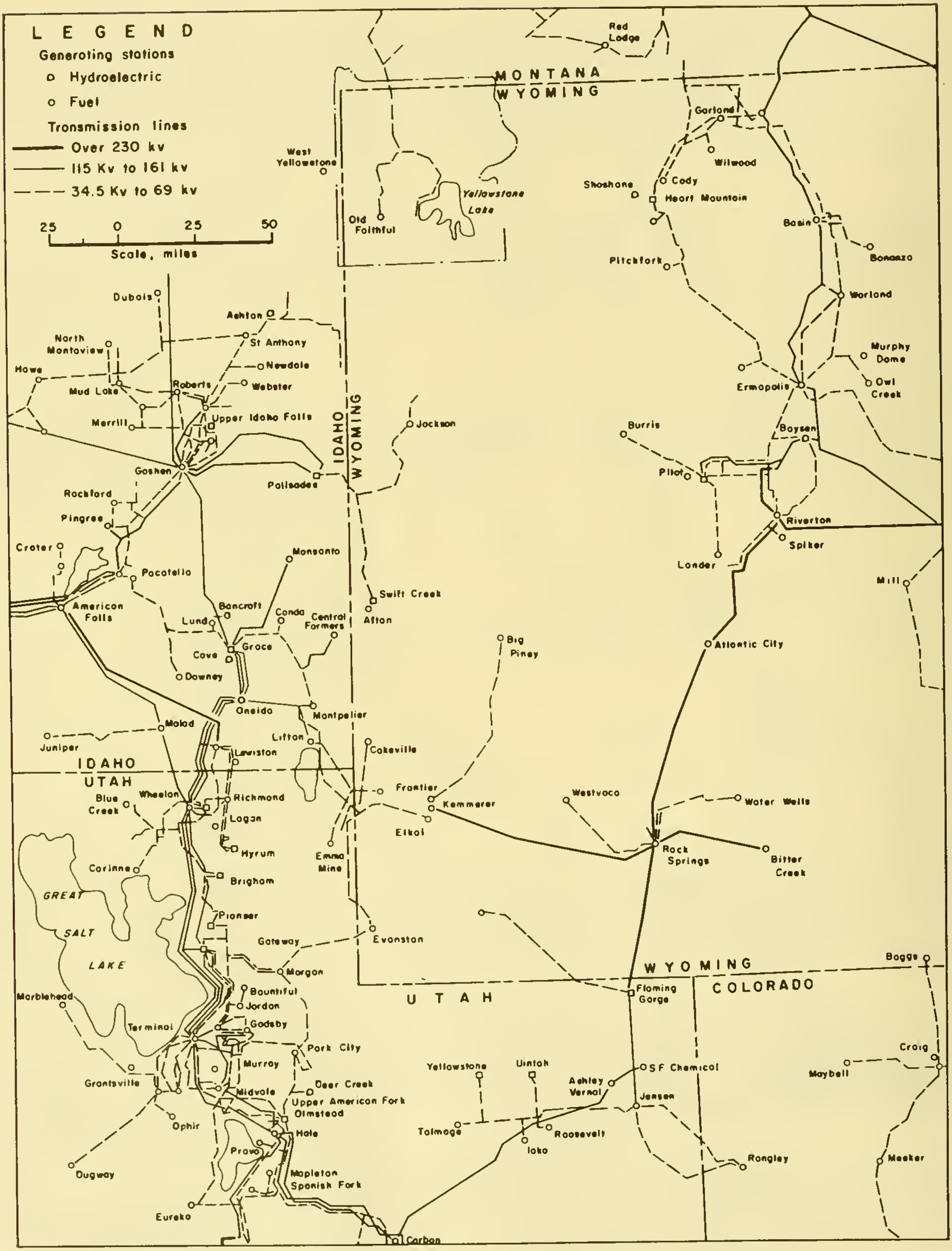

FIGURE 5. - Power Facilities in Part of the Western Phosphate Field.

Geology

The phosphate beds in Wyoming and Utah occur in the Meade Peak member of the Permian Phosphoria formation. Phosphatic rocks also occur in the Mississippian Brazer limestone in certain localities in Utah (10, p. 13), but the beds are small and do not add appreciably to the potential resources in the State.

The Phosphoria formation lies in a number of different structural settings throughout the Wyoming-Utah field. In general, there is a basic difference between the western and eastern sections; the Western belt, occuring in the thrust mountains in western Wyoming, northern Utah, and southeastern Idaho, is generally highly folded with predominantly steep dips and complex faulting. Deposits to the east, however, occur in the uplifted Wind River and Uinta Ranges and are comparatively horizontal with very little faulting. The deposits in this eastern section are thinner and usually of lower grade than those in the more complex western section.

The mountain ranges in the folded belt in western Wyoming all have similar basic structures controlling the major topographic features. Most of the main ridges are lying on the upper plate of thrust faults normally occurring near the base of the eastern side of the ridge. The stratigraphic section above the thrust may begin with Silurian or Devonian rocks but, in general, the fault rides higher in the section near the Mississippian or Pennsylvanian intervals. This upper plate stratigraphic section may exist through the upper Mesozoic where Jurassic rocks (rarely Cretaceous) occur as cap rocks on the highest ridges. These thrust faults generally override upper Mesozoic (frequently Cretaceous) rocks which are softer, forming foothill topography adjacent to the more precipitous ridges (fig. 6).

Stratigraphic displacement of the faults vary and, in many places, older Mesozoic sediments are lying on younger Mesozoics. However, there are places where Devonian rocks are thrust over Upper Cretaceous. The larger thrusts are visible over considerable distances (up to 15 to 20 miles) and, in many cases, extend as inferred exposures under recent alluvial sediments. The areas between these large thrust faults are highly folded and faulted by smaller thrusts and normal faults. In some localities, as in the western front of the Snake River Range, the phosphate strata have been crushed and broken by these secondary structures until bedding is practically indistinguishable. Throughout most of the thrust belt, the dip of the Phosphoria and related formation is near vertical to overturned; regional dips are to the west.

The western Wyoming thrust belt extends south to northern Utah where it has influenced the Phosphoria and Park City formations for some distance in the Wasatch Range. In the central and southern Wasatch Range, the regional north-south strikes of the structures are interrupted by granitic intrusions normally exposing older rock series than those exposed in the Wyoming and northern Wasatch areas. Many of the phosphate exposures are affected by local intrusions and, in some cases, the Park City formation is intersected by intrusive rocks. The region affected by the intrusives encompasses the Salt Lake City-Park City-Heber area. From this vicinity the trend of the

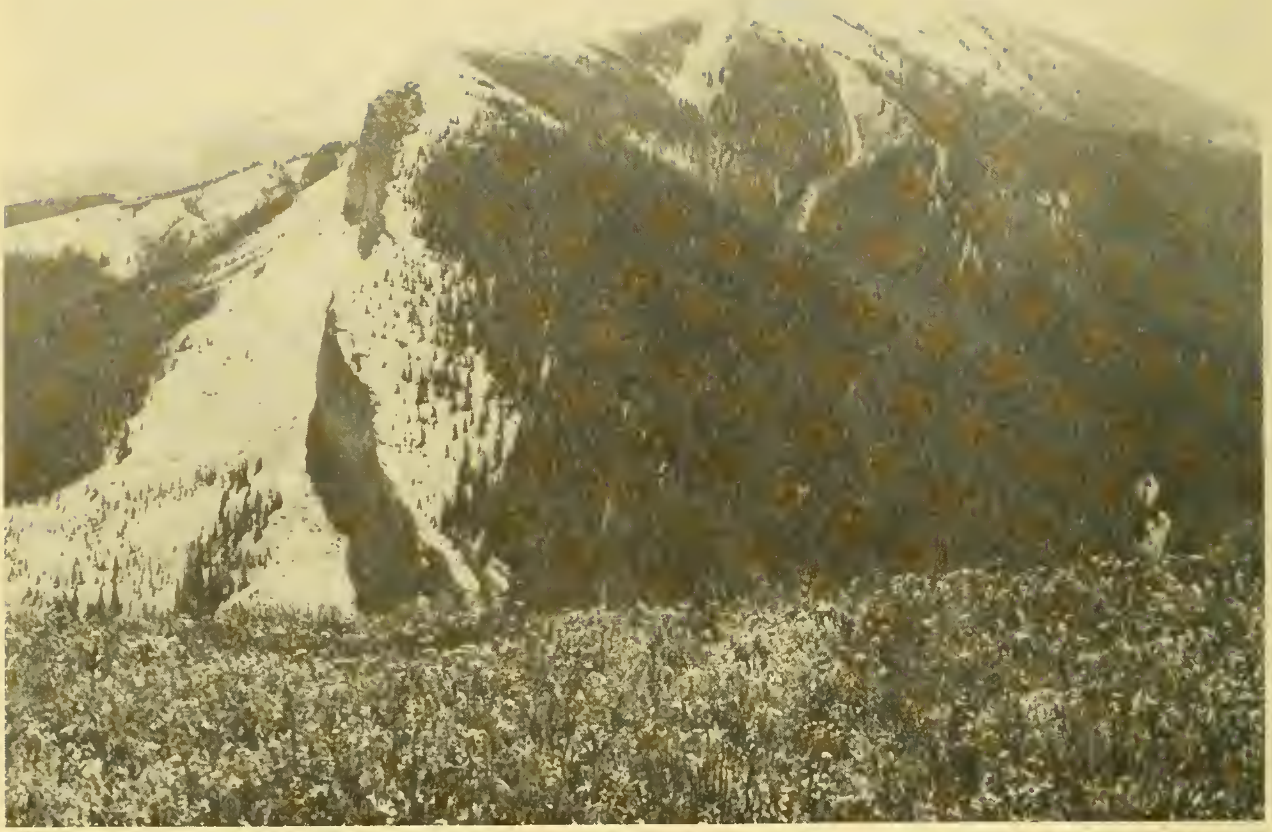

FIGURE 6. - Fault Block (Paleozoic) Overriding Mesozoic Sediments on the Left. Ridge lies on the Darby overthrust.

Phosphoria continues to the south where it has been recognized in the area east of Nephi, Utah.

In the Park City area, the carbonate rocks of the Park City formation are the principle hosts for mineralization and several lead-zinc-silver mines operated in the area during the early 1900's. Phosphate beds have been intersected in underground headings in several mines; however, no importance, neither economic nor academic, has been placed on them. Much of the data concerning grade and thickness were never recorded.

The predominant structural characteristic in the remainder of the Wyoming-Utah field is that of simple uplift. On the northeastern flank of the Wind River Range, the Phosphoria formation dips between 10° and 20° NE. On both the north and south flanks of the Uinta Mountains, the formations are affected by the uplift with almost no influence from secondary folding. The north flank dips up to 50°, but the southern flank is nearly horizontal (±8°) in most of the area where commercially significant phosphate deposits occur. To the west the attitude of the beds is steeper, but the phosphate occurrences are low grade.

Stratigraphy

A recent Geological Survey publication has simplified the Phosphoria terminology and carries the phosphatic shale section as the Meade Peak member and tongue throughout the Western phosphate field (38). In areas where the Phosphoria formation is identifiable as originally described, the Meade Peak is given member status, but in areas where Park City lithologies dominate, the Meade Peak is termed a tongue of the original member.

The Phosphoria and Park City formations are composed of 11 recognized members; the Meade Peak and Retort being the phosphatic members. The entire series rests on Pennsylvanian and Permian rock units throughout the Western field; in the southern exposures of the Park City the basal formation is the Diamond Creek sandstone. Farther north this unit grades to the Weber sandstone which continues through most of northern Utah; in Wyoming the sandstone retains a similar lithology but is known as the Tensleep sandstone. The Tensleep and the Weber formations form very distinctive outcrops in the Wind River and Uinta Ranges, respectively. Throughout the rest of the field, in Wyoming and southeast Idaho, the basal unit is the sandy-carbonate rocks of the Wells formation (limestone).

The Grandeur member of the Park City formation, next unit above the Pennsylvanian rocks, occurs in all localities in the Western field except the eastern Uinta (Brush Creek) area, although it has never been mapped as a separate unit. It varies widely in thickness through its lateral extent and was observed to range from a very hard sandy carbonate rock to a very soft calcareous mudstone.

The Meade Peak overlies the Grandeur member, although by definition, the two members are never in contact. Where the Meade Peak is classified as a "member," the Grandeur is a "tongue" and vice versa (52, p. 63).

The Meade Peak member is thickest in the central Wasatch Mountains where it has been measured at 303 feet (12, pp. 11-17), although at this locality it has been considered as being split by about 90 feet of the normally overlying Franson member (38, p. 22). Another thick section of the Meade Peak was reported in the area east of Ogden (47, p. 4). Here, trenching revealed a thickness of 262 feet, with a relatively rich phosphatic section. Underlying the Meade Peak in this area is a +200-foot "unnamed" member with phosphatic sections at the base and top similar to normal Meade Peak occurrences.

In the main part of the field in Idaho, the Meade Peak member ranges in thickness from about 110 to 230 feet, although some areas were examined where the thickness approximated 70 to 90 feet. Some of this thinning may have been the result of faulting. Most of the active mining and development on these deposits is in areas where the thickness ranges from 150 to 180 feet. In the extreme northern part of Utah, the member ranges from about 90 feet in the overturned beds in the Laketown area to a maximum of more than 130 feet in the Crawford Mountains (12, pp. 5-10). Immediately across the border in western Wyoming, the Meade Peak member is about 100 feet thick; however, little detailed work has been done in this area on separation of the various members or tongues. The thickness of the Meade Peak member, from the base of the lower phosphate zone to the top of the upper phosphate zone, has the following approximate range in phosphate districts of Wyoming and Utah:

	Thickness, feet
Wyoming:	
Snake River..................	30-50
Salt River....................	40-105
Sublette......................	95-110
South Ridges..................	45-55
Tump..........................	60-85
Hoback........................	45-55
Wind River:	
Retort......................	40-50
Meade Peak..................	0-10
Utah:	
Uinta:	
North Flank.................	45-95
South Flank.................	20-80
Wasatch.......................	90-300
Crawford Mountaina............	100-130

The main zones of phosphate enrichment are at the base and top of the member; however, there are exceptions. In most of the Snake River Range the phosphate content of the upper zone is negligible. This is also true in parts of the other districts as well. On the south flank of the Uinta Mountains, in the Brush Creek area, the phosphate content of the entire Meade Peak member (±20 feet) is fairly homogeneous as a minable section.

In the southern Wind River Mountains, the Phosphoria formation was divided into A, B, and C units in one study (28, pp. 7-8). This classification was also used in part of the Gros Ventre Range, where additional units, D and E, were identified (44, p. 10). The phosphate zones, particularly in the southern Wind River area where more study has been done, were designated as the lower (in the A member) and upper (in the B member) beds. McKelvey, however, identified the lower bed as the Meade Peak member and the upper bed as a tongue of the Retort member (38, plate 3).

SNAKE RIVER RANGE DISTRICT

General

The Snake River Range (fig. 7) is a group of extremely rugged mountains covering an area approximately 60 miles long by 20 miles wide in Madison, Teton, and Bonneville Counties, Idaho; and Teton and Lincoln Counties, Wyo. The boundary of the range on the south and southeast is the Snake River, separating the Salt River and Hoback Ranges to the south, and the Gros Ventre Range to the east. Teton Valley and Upper Teton River-Trail Creek (Wyoming) drainages separate the Snake River Range from the Teton Range to the east and northeast, respectively.

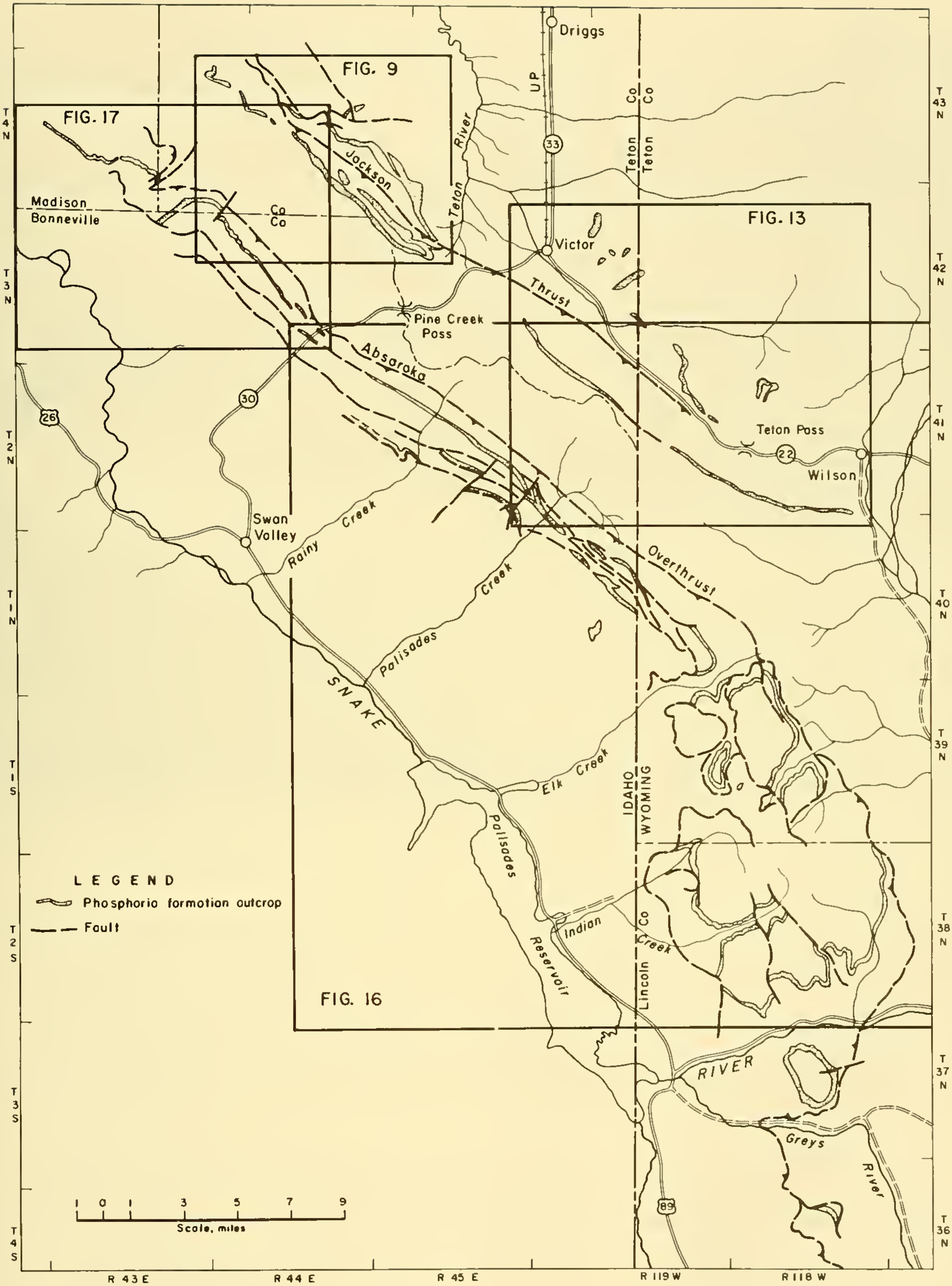

FIGURE 7. - Snake River Range District.

FIGURE 8. - Fault Slices of the Meade Peak Member on Idaho State Highway 31.

Abrupt relief up to 3,000 feet is common in the area. The majority of the valley floor elevations are between 5,500 and 6,500 feet, and the high ridges and peaks generally range between 7,500 to 9,000 feet. Several main highways encircle and cross the Snake River Range. These roads cut through fault segments of the phosphate in a few places (fig. 8), but usually the undisturbed outcrops can be reached only by jeep roads or trails. In addition to the highways, a spur line of the Union Pacific Railroad, ending at Victor, Idaho, serves the Teton Valley.

Practically all of the phosphate deposits in the Snake River Range are within the boundaries of the Targhee and Teton National Forests and are covered by Federal phosphate lease regulations. The only exceptions are in the western side of the Teton Valley, where some of the outcrops enter private land for short distances before being covered by valley alluvium. The Snake River Range is delineated by topographic maps, and aerial photographs covering the district are available at U.S. Forest Service offices in Ogden, Utah, and Boise, Idaho.

Several geologic surveys have included parts of the Snake River Range; however, the majority have been of a reconnaissance nature. The most important fieldwork relating to the phosphate resources included several trenches across the Meade Peak member and analyses of the various phosphate beds (21). The area has been of recent interest to the Geological Survey in order to classify and map withdrawn phosphate lands. Several trenches have been excavated, and the Meade Peak and Retort members have been sampled to determine their phosphate content. Project analysis work is currently underway; results of the samplings are not yet available.

Geology

The structure of the Snake River Range is characterized by a large concentration of thrust faults and associated folds plunging under the Snake River lava plain on the north. Most of the major thrusts of the western Wyoming folded belt extend through this area and, with numerous other smaller thrusts and normal faults, tend to make the range an area of extremely complex structure.

The Absaroka fault is the largest continuous thrust fault affecting the phosphate deposits in this area. Phosphoria exposures in the northwestern Snake River Range lie stratigraphically within a few hundred feet of this fault. The Big Hole Mountain and the northeastern sections of the Snake River Range are continuations of the same structures. The phosphate outcrops are usually underlain by major thrust faults, and in the Big Hole Mountains the outcrops trace a series of closely spaced folds.

The Phosphoria formation in the Snake River Range approximates 200 feet in thickness, generally including from 20 to 40 feet of the basal Meade Peak phosphatic shale member. It is underlain by the Wells formation, a limestone unit, but grading to a sandy limestone and highly calcareous sandstone in the Snake River Range. The basal member of the Phosphoria is the Grandeur which is immediately overlain by the Meade Peak. The rock type of the Meade Peak member in this area is fairly consistent with respect to the phosphate-bearing beds; the main zone is concentrated at the base, and a thinner zone lies at the top. Actual grade and thicknesses of the individual phosphate beds, however, may vary considerably from place to place.

The lithology of the Meade Peak member generally runs as follows: At the base there is a zone of phosphate rock, phosphatic shales, with minor interbeds of mudstone, shale, and carbonate rocks. This zone may range from 7 to 12 feet in thickness. Above the phosphate there occurs an interval of highly carbonaceous shales ranging from 5 to 15 feet in thickness, normally followed by 10 to 20 feet of barren mudstone and sandstone with minor interbeds of phosphate rock. At the top there is usually a 4- to 5-foot interval of carbonaceous, phosphatic shale capped by a thin phosphate bed. The Retort member also contains a thin bed of phosphate normally occurring between 75 and 150 feet above the Meade Peak. An anomalously thick section of this member occurs south of Victor, Idaho, in an outcrop recently trenched by the Geological Survey.

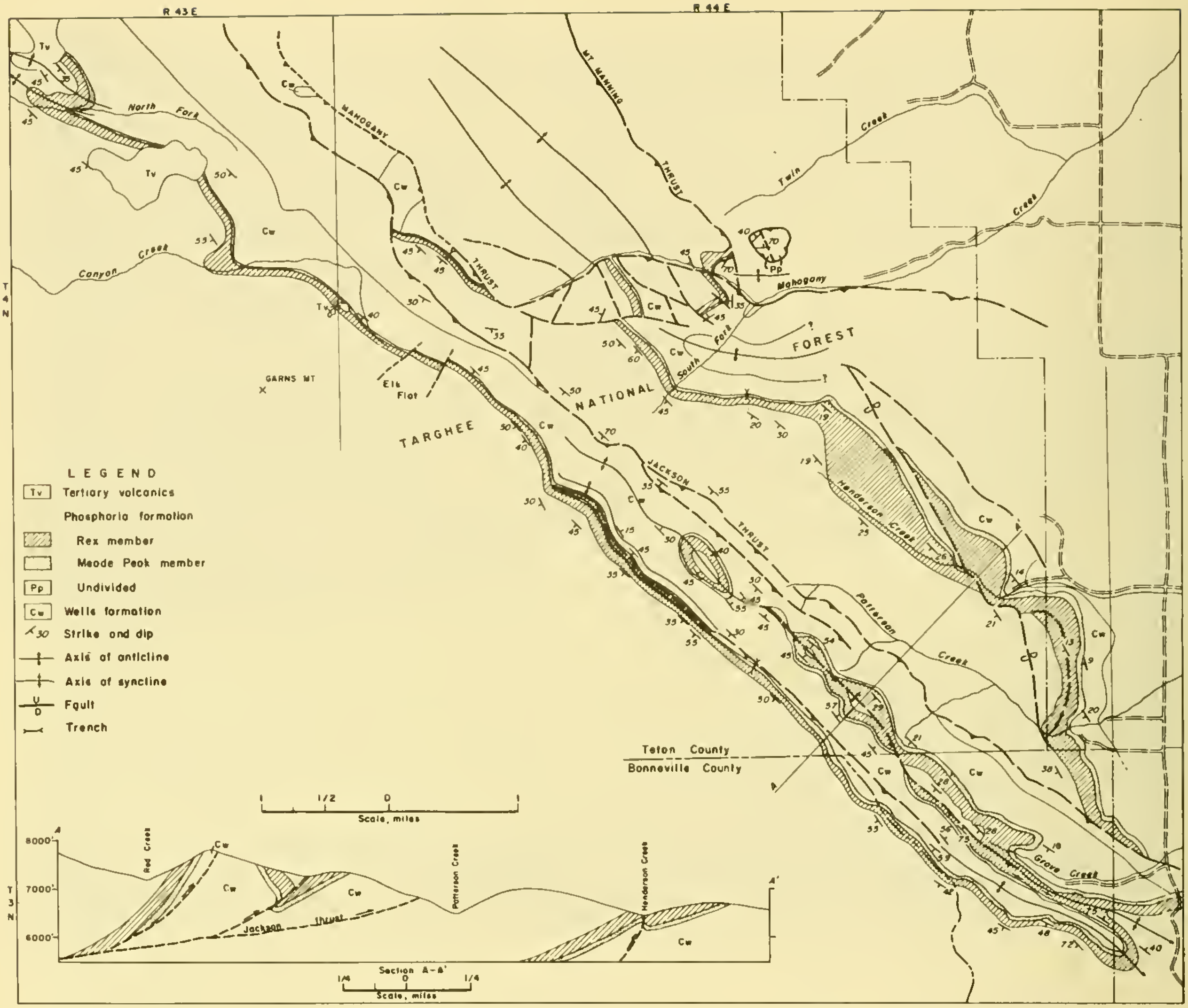

FIGURE 9. - Big Hole Mountains (17, 27). (Modified from Albee, Espach, Gardner 1944, Kilsgaard Royce, Staatz.)

A deviation from the normal lithology appears to occur in the northwestern area of the Snake River Range where the Meade Peak member was trenched by the Geological Survey in 1963. About 50 to 60 feet of the member was exposed. The section has a 6-foot basal phosphate bed overlain by approximately 40 to 50 feet of highly carbonaceous sediments, which is in turn overlain by 3 feet of cherty phosphate. The entire Meade Peak interval appears to be higher than normal in phosphate content. Several small faults can be recognized within the soft carbonaceous section, and overall thickness cannot be accurately determined.

Big Hole Mountains

The Big Hole Mountains (fig. 9) are a northwest-trending group of ridges extending from the Snake River Range and covering an area approximately 15 miles long and 6 miles wide; the phosphate belt covers an area within the mountains of about 11 by 2 miles. The topography is rugged, and the drainage pattern is controlled mainly by the geological structures. The wide Teton River valley borders the mountains on the east. Heavy vegetation and thick forest cover indicates a relatively high amount of precipitation.

Idaho State Highway 33 from Rexburg is the main access route to the area, and a spur line of the Union Pacific Railroad ends at Victor, roughly four miles east of the southernmost Phosphoria outcrop. Other access routes are from Jackson, Wyo. (25 miles), and Swan Valley, Idaho (25 miles). Access to most of the drainage entry points in the Big Hole Mountains is comparatively easy, representing no more than 12 miles of travel from Driggs or Victor. Most of the valleys contain abandoned logging roads that either cross or nearly reach the outcrops. On the northern end, where the Phosphoria crosses the North Fork of Canyon Creek, the access route is from Rexburg, a distance of 20 to 25 miles.

Geology

The structure of the Big Hole Mountains is similar in most respects to the Snake River Range. One of the most significant features is the high concentration of large scale, northwest-striking thrusts on which several fault plates lie in an imbricate pattern. They are comparable to the rest of the structure in the area and are often broken and offset by reverse and normal cross faults. Although the predominant dip is to the southwest, the sediments between the thrusts are sometimes highly folded.

The Big Hole Mountains contain sedimentary rocks ranging in age from Mississippian to upper Cretaceous. The base of the Mississippian is not exposed, but the Pennsylvanian and Permian beds have a total thickness of approximately 1,200 feet. The Mesozoic section is in the order of 10,000 feet in this area. Tertiary volcanic rocks overlap all of the sediments on the north end and in two small areas, immediately east of Garns Mountain, they cover the Phosphoria formation. The lithology of the volcanic sequence is rhyolite interbedded with some basalts and minor tuff beds.

The Phosphoria formation crops out for a total distance of about 30 miles over an area of 25 square miles in the Big Hole Mountains. It lies in a northwest-striking pattern along three main belts that may be described from west to east as the western trend, the middle syncline, and the eastern trend. The western trend extends relatively continuously for a distance of about 12 miles, and the remainder of the outcrop length (18 miles) is more or less equally divided between the middle syncline and the eastern trend. There are several other small exposures of the Phosphoria in the Big Hole Mountains; however, these are highly disturbed fault slices and are not considered as potential resources.

The thickness of the Meade Peak member varies between 30 and 35 feet in the Big Hole Mountains, and nearly all of the phosphate enrichment is localized in the lower 15 feet. The main phosphate zone lies on a sandy carbonate rock and generally ranges from 3.5 to 7.5 feet in thickness; there appears to

FIGURE 10. - West Dipping Phosphoria Formation. Ridge crest is the Rex-Franson interval.

be a thickening toward the north. The zone is either split or capped by 1.5 to 2.5 feet of hard, calcareous mudstone, and overlain by 4 to 8 feet of carbonaceous, phosphatic shale. The remainder of the overlying Meade Peak section, with the exception of a few very thin isolated beds, is relatively barren of phosphate.

The western trend, extending south from the North Fork of Canyon Creek to the Teton valley, is the longest continuous outcrop of the Phosphoria formation in the area (fig. 10). It lies on the southwest flank of a relatively tight anticline and can be traced throughout most of its length. Dips vary inconsistently between 35° and 75° SW although in most places they range from 45° to 60°. At the north end the anticline is rather sharp, and the Phosphoria formation traces a complimentary syncline to the east before the outcrop is covered by volcanics. The formation is also covered in two places along the outcrop farther to the south, a total length of about one-half mile, by these flat lying volcanics. This synclinal structure does not extend south of the North Fork of Canyon Creek, as indicated by the west-dipping beds.

In the headwaters of the South Fork of Mahogany Creek, a strike fault has been mapped for about one-half mile (1), and there is an unusual thickening of the formation in this vicinity. In addition, there is localized faulting and some structural complications where the phosphate is covered by volcanic rocks.

The main outcrop on the western trend was trenched and sampled in an earlier survey (21, pp. 28-29), and recently it was deepened and resampled by the Geological Survey (table 10). Another trench (21, pp. 27-28) was excavated and sampled, and similarly resampled, in a fault block offset about 1 mile to the east of the main outcrop (table 11). In the few feet of deepening by the recent trenching, the phosphate beds appear slightly thinner; thicker beds apparent near the surface are probably the result of expansion due to weathering and unloading. The phosphatic section in these trenches indicates a general increase in phosphate content of the basal bed toward the north. A relatively large amount of high-grade float occurring on the main outcrop toward the North Fork of Canyon Creek may indicate either an increase in thickness and/or an increase in grade of the basal bed.

TABLE 10. - Detailed section of Meade Peak member in trench F[1]

Lithology	Thickness, feet	Analyses, percent					
		P_2O_5	CaO	Fe_2O_3	Al_2O_3	Loss on ignition	Insoluble residue
Sandstone................	2.7	-	-	-	-	-	-
Phosphate rock...........	0.1	24.3	35.6	1.9	3.6	5.4	21.4
Siltstone................	5.7	-	-	-	-	-	-
Phosphate rock...........	2.0	20.8	30.6	2.1	4.0	8.3	26.8
Sandstone................	8.4	-	-	-	-	-	-
Siltstone................	0.4	0.8	3.0	4.4	5.1	8.3	77.2
Siltstone................	0.6	-	-	-	-	-	-
Phosphatic siltstone.....	2.1	10.5	16.0	3.5	5.1	13.1	46.3
Phosphate rock...........	2.7	14.2	21.9	2.5	4.8	14.5	34.7
Phosphate rock...........	2.6	23.5	34.4	1.9	3.7	8.5	20.6
Siltstone................	2.2	-	-	-	-	-	-
Phosphate rock...........	1.0	24.0	35.1	1.9	4.2	6.3	21.7
Phosphate rock...........	1.2	36.3	52.0	0.8	0.5	3.3	1.8
Phosphate rock...........	1.1	28.9	41.8	1.0	0.8	2.4	20.7

[1] (21, pp. 28-29).

The middle synclinal structure extends about six miles north from Teton valley to the South Fork of Mahogany Creek. Total outcrop length on both limbs is about 6 miles. The Meade Peak member is exposed on the surface for about 4 miles. The structure plunges to the south and eventually disappears in a southwest dipping fault complex. The Phosphoria formation has been eroded from the north end, and younger sediments are exposed before the structure is faulted out. The phosphate member extends south on the west limb of the syncline and traces the adjacent anticline to the west. On the southern end, the east limb exposures are covered by valley alluvium before they turn and join the structure to the east.

The phosphate member is exposed on the slopes of a series of structurally aligned saddles that become increasingly sharp from south to north. There are comparatively wide areas exposed on these saddles where significant tonnages of ore could be developed. A prominent fault follows the trough of the syncline and visibly displaces the formation in exposed areas. The structure is assymetrical and the steepest dips are on the west limb; dips tend to increase to the north. A considerable length of shales that dips nearly vertically is exposed on the southern part of the west limb.

TABLE 11. - Detailed section of Meade Peak member in trench E[1]

Lithology	Thickness, feet	Analyses, percent					
		P_2O_5	CaO	Fe_2O_3	Al_2O_3	Loss on ignition	Insoluble residue
Shale.....................	18.1	-	-	-	-	-	-
Phosphate rock............	0.8	30.2	44.5	1.3	1.8	5.5	6.9
Sandstone.................	0.9	-	-	-	-	-	-
Phosphatic shale..........	0.3	12.5	19.6	2.9	5.4	15.2	36.9
Sandstone.................	0.2	-	-	-	-	-	-
Phosphatic siltstone......	1.8	10.2	16.9	2.8	3.9	14.8	45.5
Phosphate rock............	0.1	20.9	33.5	1.5	2.8	15.2	16.3
Phosphatic limestone......	1.0	8.2	26.7	1.5	1.5	26.4	23.2
Limestone.................	0.2	-	-	-	-	-	-
Phosphatic limestone......	0.5	5.6	31.2	0.4	0.4	40.7	4.0
Phosphate rock............	0.3	23.5	36.9	0.6	2.4	14.3	11.1
Phosphatic limestone......	0.5	4.9	29.6	0.4	0.6	40.8	5.8
Phosphate rock............	1.0	23.4	35.6	1.3	2.3	13.4	14.3
Phosphatic limestone......	0.3	7.3	25.1	1.9	1.8	27.6	23.0
Phosphate rock............	0.8	19.5	29.9	1.6	3.1	15.0	22.3
Phosphatic shale..........	0.2	13.0	21.7	2.1	3.2	19.7	31.6
Limestone.................	0.3	-	-	-	-	-	-
Phosphate rock............	0.6	15.4	25.5	1.6	3.4	20.9	26.1
Limestone.................	0.1	-	-	-	-	-	-
Phosphate rock............	0.5	29.8	43.8	1.3	1.4	8.7	6.7
Chert.....................	0.1	-	-	-	-	-	-
Phosphate rock............	0.8	33.2	48.8	0.3	0.3	5.8	4.5
Phosphate rock............	0.7	34.3	49.0	0.5	0.7	3.6	5.3
Phosphatic shale..........	0.3	11.4	18.5	2.5	5.0	19.7	37.5
Phosphatic shale..........	0.3	8.4	13.6	3.8	5.8	12.3	52.7
Phosphate rock............	1.5	35.7	52.2	0.4	0.6	2.9	2.9

[1] (21, pp. 27-28).

The eastern trend phosphate exposures extend approximately 9 miles, dip to the southwest, and are cut by several faults lying in an imbricate pattern. The outcrop parallels the middle synclinal structure and is apparently faulted off at both ends. A section of the phosphate beds near the middle of the structure is repeated by a paralleling thrust fault.

A nearly continuous outcrop of the phosphatic shale member extends north from Henderson Creek to the North Fork of Mahogany Creek where it is faulted out by a complex anticlinal structure in Triassic rocks. The beds dip from 20° to 60° W with the steepest dips in the northern section of the exposure (fig. 11). Faulting has complicated the structure near Henderson Creek, and a faulted segment of the Phosphoria formation, about 1.5 miles long, has been mapped in the area north of the creek. The surface is covered with a dense growth of timber and detailed examination was difficult. The southern extension of this same trend continues from Henderson Creek to Grove Creek where it

FIGURE 11. - West Dipping Meade Peak Member (Dark) on the South Fork Mahogany Creek.

is covered by valley alluvium. The outcrops approach a major thrust fault at this point, but surface details are masked by dense undergrowth and timber. The beds dip from 10° to 20° W and strike generally northwest.

The Meade Peak outcrop was trenched and sampled (table 12) on the divide between the South Fork of Mahogany Creek and Henderson Creek (fig. 12). The beds recorded in this trench (21, p. 26) were still in fairly good condition during the Bureau of Mines investigation in 1964.

TABLE 12. - Detailed section of Meade Peak member in trench D[1]

Lithology	Thickness, feet	Analyses, percent					
		P_2O_5	CaO	Fe_2O_3	Al_2O_3	Loss on ignition	Insoluble residue
Mudstone..................	4.0	-	-	-	-	-	-
Phosphate rock............	0.3	32.0	48.3	1.0	1.1	5.3	3.5
Mudstone..................	0.4	-	-	-	-	-	-
Phosphate rock............	1.9	18.9	29.4	1.8	3.1	15.7	21.9
Sandstone.................	5.3	-	-	-	-	-	-
Mudstone..................	4.2	-	-	-	-	-	-
Phosphatic shale..........	1.0	12.6	-	-	-	-	-
Shale.....................	0.9	-	-	-	-	-	-
Phosphate rock............	1.1	25.0	37.4	1.1	2.2	12.9	13.3
Shale.....................	0.7	-	-	-	-	-	-
Siltstone.................	0.8	1.4	25.8	1.0	0.5	40.4	13.1
Phosphate rock............	1.5	18.8	28.5	1.5	3.7	14.5	25.3
Phosphate rock............	1.1	15.2	23.7	2.0	3.1	19.0	26.3
Phosphatic sand...........	0.4	-	-	-	-	-	-
Phosphate rock............	0.8	19.2	30.3	1.9	3.2	14.8	21.0
Phosphate rock............	0.6	23.7	-	1.9	4.0	-	29.3
Phosphate rock............	0.8	33.2	49.2	0.5	0.3	5.4	2.5
Mudstone..................	0.5	-	-	-	-	-	-
Phosphate rock............	1.3	27.2	45.6	0.5	0.6	1.3	3.2
Mudstone..................	1.4	0.4	25.5	1.1	0.7	38.2	16.4
Phosphate rock............	1.9	31.2	45.8	0.9	0.5	3.5	12.3

[1] (21, p.26).

Resources and Potential

In the three trenches excavated by the Geological Survey in the Big Hole Mountains, the basal phosphate bed (+24 percent P_2O_5) was found to range from 3.3 to 5.1 feet in thickness. Another, sometimes adjacent, low-grade bed overlies the basal phosphate bed and ranges from 3.8 to 7.4 feet in thickness. In the northernmost trench a 4.1-foot low-grade bed appears still higher in the section (table 13). These trenches are considered to represent the eastern and western trends, on or near which they occur.

On the synclinal structure no sampling data is yet available. The only indication of grade on this outcrop is the relatively large amount of high-grade float occurring on the exposure.

TABLE 13. - Possible mining sections in the Big Hole Mountains

Lithology	Thickness, feet	Weighted average percentages					
		P_2O_5	CaO	Fe_2O_3	Al_2O_3	Loss on ignition	Insoluble residue
Trench D:							
Waste	20.6	-10	-	-	-	-	-
Phosphatic shale[1]	3.8	15.9	24.4	1.6	3.0	14.3	22.0
Phosphate rock[1] [2]	5.1	26.6	36.4	0.8	0.9	2.5	9.2
Trench E:							
Waste	18.1	-10	-	-	-	-	-
Low grade[1]	4.1	11.8	18.4	1.7	2.5	9.0	24.4
Waste	1.7	-10	-	-	-	-	-
Low grade[1]	4.1	15.3	27.4	1.2	2.2	18.3	16.4
Phosphate rock[1]	4.2	29.8	43.6	0.9	1.3	6.1	10.0
Trench F:							
Waste	19.9	-10	-	-	-	-	-
Phosphatic siltstone and phosphate rock	7.4	16.4	24.6	2.6	4.5	12.0	33.0
Waste	2.2	-10	-	-	-	-	-
Phosphate rock	3.3	30.1	43.5	1.2	1.7	3.9	14.1

[1]Analyses are approximate since no estimates were made for the small waste beds not analyzed.

[2]Interval split by 1.4-foot hard mudstone waste. The total thickness of the interval is 6.5 feet.

Based on the above measured and assumed possible mining thicknesses, the phosphate resources of the Big Hole Mountains are shown in table 14.

TABLE 14. - Phosphate rock resources in the Big Hole Mountains (million short tons)

Locality	Grade, percent P_2O_5					
	+24		+18		+10	
	Above entry	100 feet below	Above entry	100 feet below	Above entry	100 feet below
Western trend	16.6	2.8	36.5	6.1	46.2	7.1
Syncline	14.3	-	23.6	-	23.6	-
Eastern trend	16.5	3.0	26.0	4.7	26.0	4.7
Total	47.4	5.8	86.1	10.8	95.8	11.8

These resources are estimations of the rock in place taken to the most likely drainage level and 100 feet below entry. A recent estimate by the Geological Survey lists the above entry phosphate resources as 63.0 (+24 percent P_2O_5) and 120.3 (+18 percent P_2O_5) millions of short tons (52, p. 154).

Another important factor that will affect development of the Big Hole phosphates is the strength characteristics of the rock beds. The basal (+24 percent P_2O_5) bed consists of 2 or 3 alternately soft and hard layers. The overlying (+15 percent P_2O_5) horizon is generally highly carbonaceous and quite soft where exposed in trenches. If the entire interval could be mined

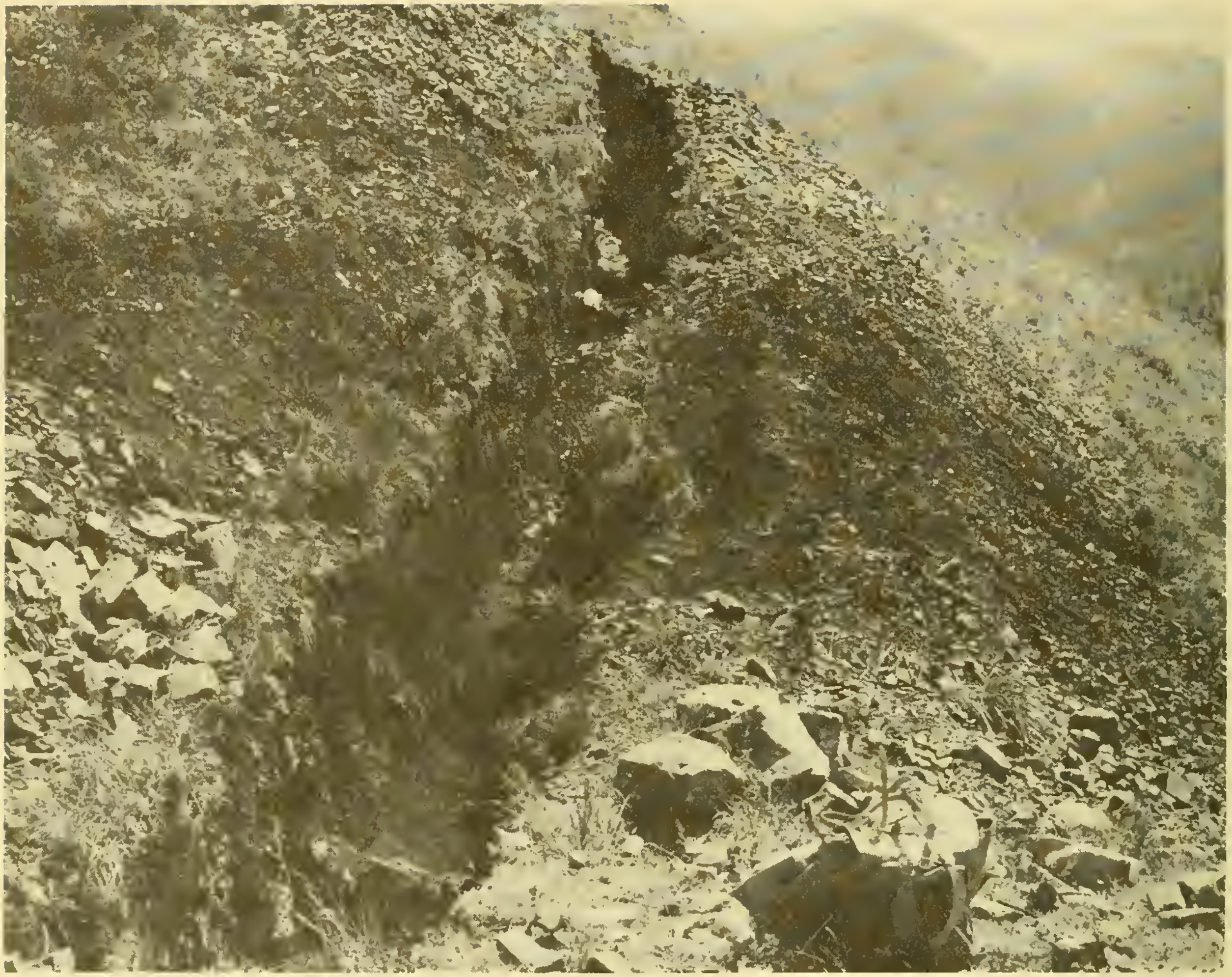

FIGURE 12. - Hand Trench in the Meade Peak Member on Mahogany Ridge.

(approximately 8 to 11 feet of +18 percent P_2O_5 rock) there would be no problem of caving. The overlying mudstone-shale-phosphate rock sequence is hard and would probably stand quite well. Also, it is possible that the +15 percent bed would become stable at depth. The main problem of sloughing of this type of rock has been in folded deposits and not so much in the simple tilted strata. Before a method of extraction could be decided upon, the factors of selective versus bulk mining, and single versus double processing would have to be considered.

The Teton valley to the east is well situated for both rail transportation and as a site for processing facilities. Development of the Big Hole deposits might follow the pattern of one underground operation in Montana. Near Douglas Creek the ore is upgraded from 18 to 22 percent to +31 percent by flotation. It is conceivable that the rock in the Big Hole Mountains could be similarly upgraded. Thus, it remains for favorable market conditions and a decrease in the availability of ore or phosphate land in the rest of the field to promote active exploration and development.

Underground methods would probably be used to mine the majority of resources in the Big Hole Mountains area. In general, the topography, with many deep canyons and steep interstream ridges, eliminates the possibility of open pit development. In addition, the majority of the Meade Peak exposures dip into the hill or lie under a +20-foot Rex-Franson cap. This, along with the +25-foot waste section and an average 10- to 15-foot depth of overburden, would mean an excessive waste to ore ratio in an open pit operation.

In the synclinal structure, however, where the Meade Peak dips off the hill, there is roughly 1.5 million tons of +24 percent P_2O_5 rock that may possibly be mined by open pit methods. A mining depth of 50 feet and a topographic loss of 50 percent were used to arrive at this figure.

Northeastern Snake River and Southern Teton Ranges

Northeastern Snake River Range

The Northeastern Snake River Range (fig. 13) includes the mountainous mass immediately south of the Teton Range, and is a continuation of the Big Hole Mountains structure to the northwest. It is bounded on the north by the upper Teton River (Idaho) and Trail Creek (Wyoming). In separate studies, the western trend of the Phosphoria has been mapped both continuously in a single outcrop over a distance of about 20 miles, and as being faulted out for about two miles in the vicinity of the Idaho-Wyoming border.

As in the Big Hole Mountains, the topography is rugged and access is limited. Idaho State Highway 33-Wyoming State Highway 22 traverses the north border of the area and connects the towns of Victor, Idaho, and Jackson, Wyo. The outcrop is accessible by a gravel road at the eastern end, and on the west a poor forest access road crosses the Phosphoria formation in Pole Canyon about 3 miles south of Victor. The only other access is by forest trails which follow the main drainages and some ridges.

Geology

The general structure of the area is a southwest-dipping limb of a syncline. Dips are steep, generally exceeding 60°, and there is one place west of Mount Taylor where the beds are overturned. The entire section apparently lies on the upper plate of the Jackson thrust which follows the north border of the area. This fault brings the lower Paleozoic beds of the northwest-striking Snake River Range structure in contact with the more north-striking beds affected by the Teton Range uplift.

The stratigraphy of the area is generally continuous with that of the Big Hole Mountains. All of the Mesozoic and Paleozoic formations, including the Phosphoria, are overlapped by Tertiary volcanics as they trend down to the lower slopes in the south end of the main Teton valley. Across the border in Wyoming, an outcrop of andesitic rocks was found cutting Jurassic sediments south of the phosphate outcrops.

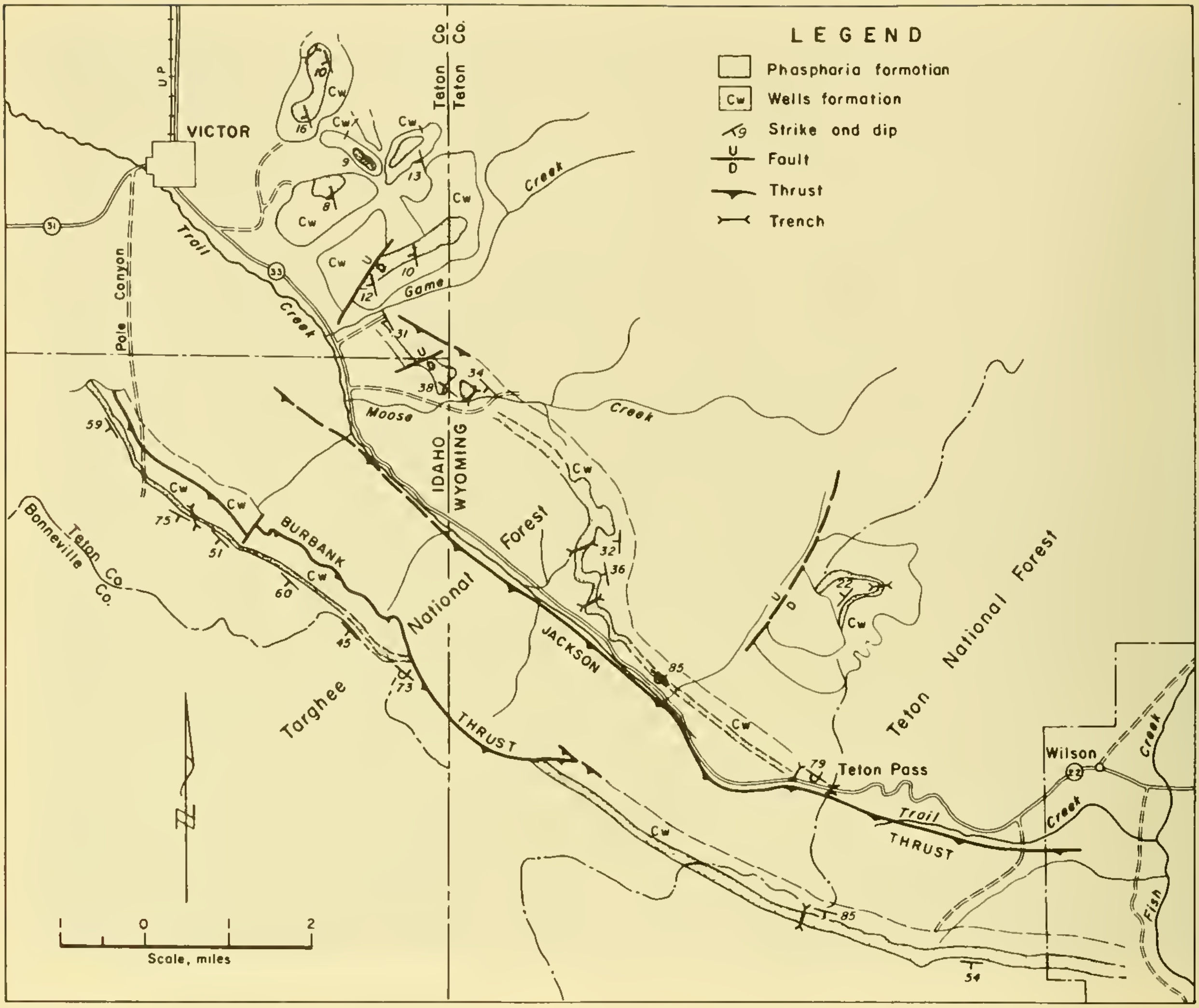

FIGURE 13. - Northeastern Snake River and Southern Teton Ranges (66). (Modified from Baillee, Gardner, 1944, Horberg, Love, Wyman.)

The Phosphoria formation extends from the hills south of Victor, Idaho, to the Snake River valley in Wyoming. In one study it was mapped as a continuous outcrop (5); however, another study shows it as being faulted out by the Burbank thrust from Oliver Peak west on strike for about two miles (65). The latter interpretation will be used in this work, since there is a relatively large difference in grade and thickness of the phosphate beds between the Idaho and Wyoming occurrences. Also, the Burbank fault offers a convenient division point for the areas of influence of the sample information on the respective segments. From its exposure on the Wyoming side, the Phosphoria extends continuously to where it is covered by terrace and alluvial deposits in the Snake River valley. Surface expressions of the Meade Peak member are usually very subdued on the Wyoming part of the outcrop.

FIGURE 14. - Hand Trench in the Meade Peak Member South of Victor, Idaho.

The Phosphoria dips steeply to the southwest throughout most of the strike length; where observed on the surface, many dips exceeded 70°. There is a section immediately west of Oliver Peak, however, that is overturned about 70° to the northeast. On the western end, dips decrease to about 50° to 60° where the Phosphoria nears the Teton valley. There appears to be a general difference in the structural character as well as grade in the Meade Peak between Idaho and Wyoming. Several obvious cross faults of comparatively small displacement occur on the Wyoming side but are not apparent in Idaho. Also, the underlying Wells formation is more broken where it is exposed in Wyoming.

The Meade Peak member was recently trenched and sampled on both the Idaho and Wyoming outcrops by the Geological Survey (figs. 14-15); however, detailed results are not available. There is a wide difference in the phosphate content of the two trenches; the Wyoming section (table 15) was comparably lean, while the Idaho trench showed an anomalously rich section for that area (table 16). The dip of the strata in both trenches ranges from 70° to 75°. The

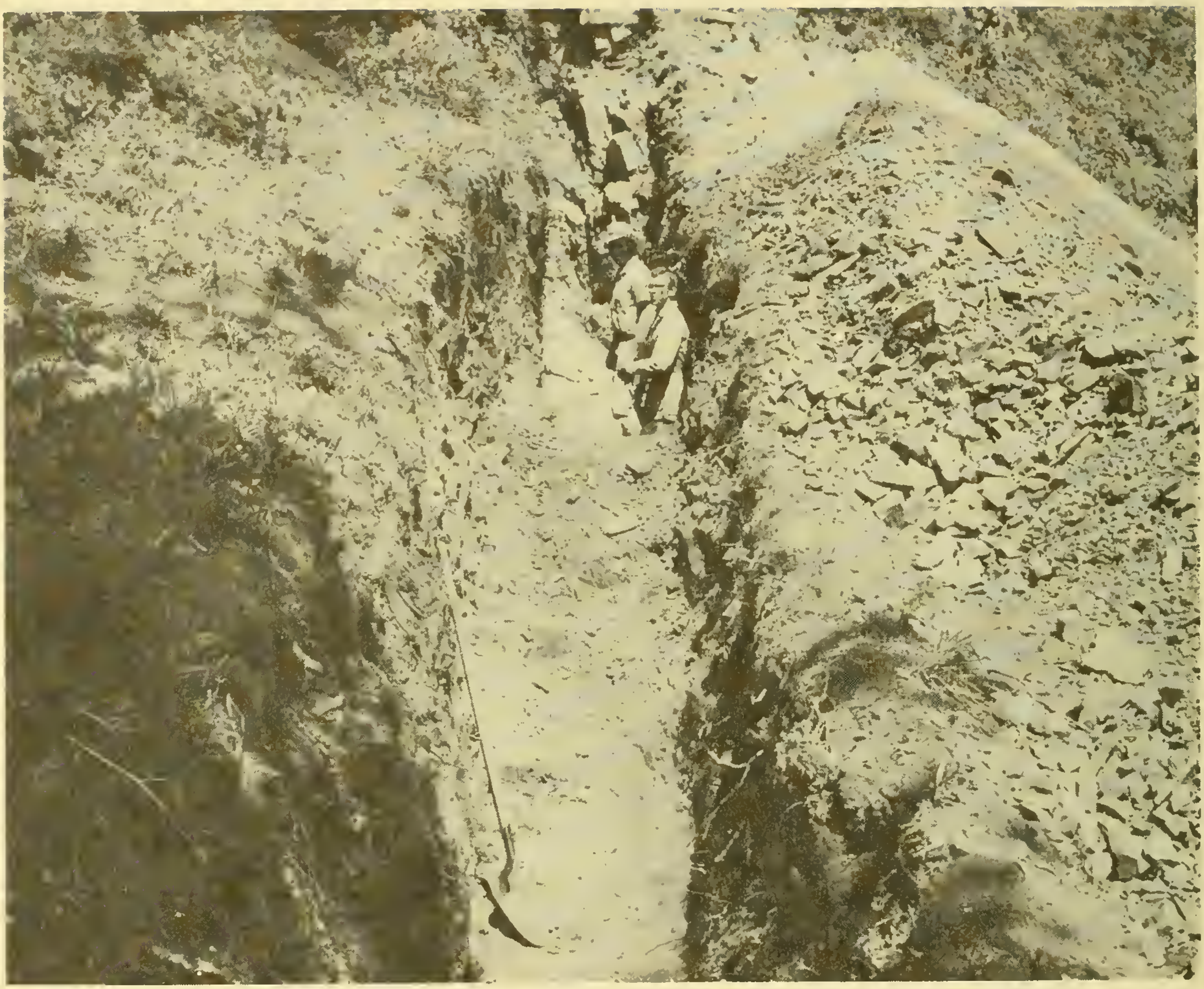

FIGURE 15. - Hand Trench in the Meade Peak Member South of Teton Pass, Wyo.

Retort member was also exposed in both trenches; it occurred roughly 70 and 100 feet, stratigraphically, above the Meade Peak in the Wyoming and Idaho sections, respectively. At the Wyoming locality the phosphatic section was negligible, however, on the Idaho side there was an exposed interval of hard cherty phosphatic rock roughly 20 feet thick. No analyses were made on this unit, but the grade may be in the +15 percent P_2O_5 category. This exposure of the Retort member is not used in resource estimates because the phosphate characteristics are very inconsistent, even over short lateral distances.

TABLE 15. - Meade Peak section, south of Teton Pass, Wyo.

Lithology	Thickness, feet
Phosphate rock, highly cherty with numerous cavity fillings of calcite	1.5
Soft mud seam with thin beds of hard mudstone and phosphate rock	2.4
Mudstone, with minor phosphate rock interbeds	5.9
Mudstone and phosphate rock interbeds, highly weathered	4.0
Mudstone, with small interbeds of phosphate rock and chert	15.0
Phosphatic shale, highly carbonaceous; with mudstone interbeds	3.8
Phosphate rock, highly weathered, interbedded, with phosphatic mudstone and shale	2.8
Mudstone with minor phosphate rock and shale interbeds	2.0
Phosphate rock, highly weathered, cherty, with some small chert bands (0.7-foot mud seam at base)	3.0
	40.4

TABLE 16. - Meade Peak section, south of Victor, Idaho

Lithology	Thickness, feet	Analyses, percent P_2O_5
Phosphate rock, hard, cherty	1.5	32.2
Mudstone with minor phosphatic beds	10.0	-
Phosphate rock, carbonaceous, highly weathered	6.0	21.2
Mudstone with minor phosphatic beds	18.0	-
Shale, phosphatic, highly carbonaceous	3.5	9.3
Shale, phosphatic carbonaceous	7.5	13.9
Phosphatic rock, highly weathered	2.7	19.3
Mudstone, phosphatic, weathered	1.8	2.6
Phosphate rock, hard, cherty, soft at top	4.0	20.7
	55.0	

Resources and Potential

In Idaho, the northeast Snake River Range resources above and 100 feet below drainage entry are shown in table 17. These figures represent tonnages based on what appears to be the most practical mining thicknesses. The most likely mining bed is the upper 6-foot, +21 percent P_2O_5 bed, bounded on both sides by thick units of hard mudstone. In the basal section it is assumed that the 1.8-foot bed splitting the higher grade zone could be wasted. In view of the anomalously thick section exposed here, there is the possibility that this deposit is localized. According to available data, the Idaho portion of the northeastern Snake River Range deposits are suited to underground mining, but details of beneficiation will have to be resolved. Transportation facilities and access to possible entry points are favorable. Steep dips and short, rugged, intervalley distances are not favorable to open pit development because of difficult road building conditions. On the western end, where the dips decrease, the Meade Peak member is dipping into the hill, thus limiting the effective open pit size.

TABLE 17. - Phosphate rock resources in the northeastern Snake River Range, Idaho
(million short tons)

Grade, percent P_2O_5	Above drainage entry	100 feet below entry
+18......................	18.5	3.2
+10......................	31.2	5.3

The Wyoming segment of this outcrop is classed as a latent resource. Access to about half the exposure is through drainages extending into the Snake River valley, which is isolated from all major transportation facilities. The part of the outcrop extending into the Teton River drainage is accessible through canyons opening out to the upper Teton River.

Since there are no phosphate analyses representing this area, grades are assumed to continue from the Big Hole Mountains, where a similar phosphate section occurs; grade was reduced from +24 percent to +18 percent P_2O_5. Based on these assumptions, total latent resources above drainage entry are estimated to be: +18 percent P_2O_5--7 million short tons and +10 percent P_2O_5--20 million short tons. Another 1 and 3 million short tons, respectively, would occur in the first 100 feet below drainage entry.

Southern Teton Range

The Phosphoria formation crops out for some distance in the southern part of the Teton Range (fig. 13). East of Victor, the main outcrop strikes southeast for about 3 miles and dips to the southwest. In its continuation eastward toward Teton Pass the formation is highly faulted and overturned to the northeast. There have been four sections sampled on this eastern extension. The westernmost section on Moose Creek (27, p. 31) was found to contain only two separate phosphate beds of about 1 foot in thickness. Farther to the east, on Talbot Creek, the section is a little richer, containing two phosphate beds, each nearly 3 feet thick (27, p. 32). Two sections were measured in another survey on Hungry Creek and in a road cut near Teton Pass. The Hungry Creek trench, about one-half mile west of the Talbot Creek trench, exposed crumpled remnants of the Meade Peak member (11, p. 10). The road cut section, west of Teton Pass, contained only a few thin beds of phosphate rock (11, p. 16).

The Phosphoria formation also crops out immediately east of Victor where it is relatively flat lying. These showings were mapped in a previous survey (21, plate 3), and the northern exposure was sampled. The Meade Peak member contained a 4.3-foot bed of +30 percent P_2O_5 rock. Apparently, this occurrence was enriched by weathering, and the zone was not projected throughout the exposure (21, p. 30). Phosphate deposits as far north as Darby Creek have been reported, but the beds are very thin (49).

Another trend of the Phosphoria formation occurs on the divide between the Snake and Teton River drainages. This exposure was hand-trenched and

and sampled by the Geological Survey in 1963. Results of the analyses are not yet available, but there is a reported 9-foot phosphatic section at the base of the Meade Peak member. The outcrop has been mapped as straddling the divide in a west-dipping attitude and is overlapped by Tertiary volcanics on the south (26). In view of a 9-foot thickness of ore, this outcrop would contain about 15 million tons of phosphate rock; however, evidence is not yet sufficient to attempt a realistic estimate. It appears that this is the only locality in the southern Teton Mountains with a section thick enough to warrant consideration in a resource estimate. Access to the outcrop is by way of several miles of Forest Service trail from the Phillips Creek road on the east side of the mountains.

Southern Snake River Range

General

The southern Snake River Range includes the area south from the Pine Creek-Little Pine Creek drainage line to the Grand Canyon of the Snake River (fig. 16). Similar topography continues south of the canyon as the Salt River Range. The area is encircled on all sides by main highways. Idaho Highway 31 crosses two fault slices of the Phosphoria formation on the north boundary of the area but, in general, the main roads are some distance from the phosphate outcrops. Several Forest Service roads branch off the highways and follow the larger drainages for comparatively short distances; it is generally necessary to walk several miles to the phosphate exposures.

This area probably represents the most rugged topography in the Snake River Range with respect to the phosphate occurrences. It includes the precipitous Grand Canyon of the Snake River near the south boundary, and all of the main streams are deeply incised. Practically all main peaks and ridges are over 9,000 feet in elevation, and the nearby canyons of the crosscutting drainages generally range from 6,000 to 7,000 feet in elevation.

Geology

The northwest trend of the phosphate belt crosses the Idaho-Wyoming State line in this district, and the general structure, compared to the rest of the Snake River Range, is very complex. The State line also approximates a natural geographic division separating two types of gross structural features that affect the Phosphoria formation.

The Idaho portion of the belt lies in a closely folded structure consisting mainly of very tight anticlines and synclines. The Phosphoria outcrops consist mainly of relatively short, highly deformed fault slices; predominant dips are steep to the southwest with some segments overturned. Typical outcrops of the phosphatic shale interval are either thinned by faulting or so deformed that the thickness appears to be 2 or 3 times normal.

On the Wyoming side, the Phosphoria extends into an area influenced by a large, northwest-trending synclinal structure. There are numerous subsidiary folds associated with the main syncline, as well as numerous large and small

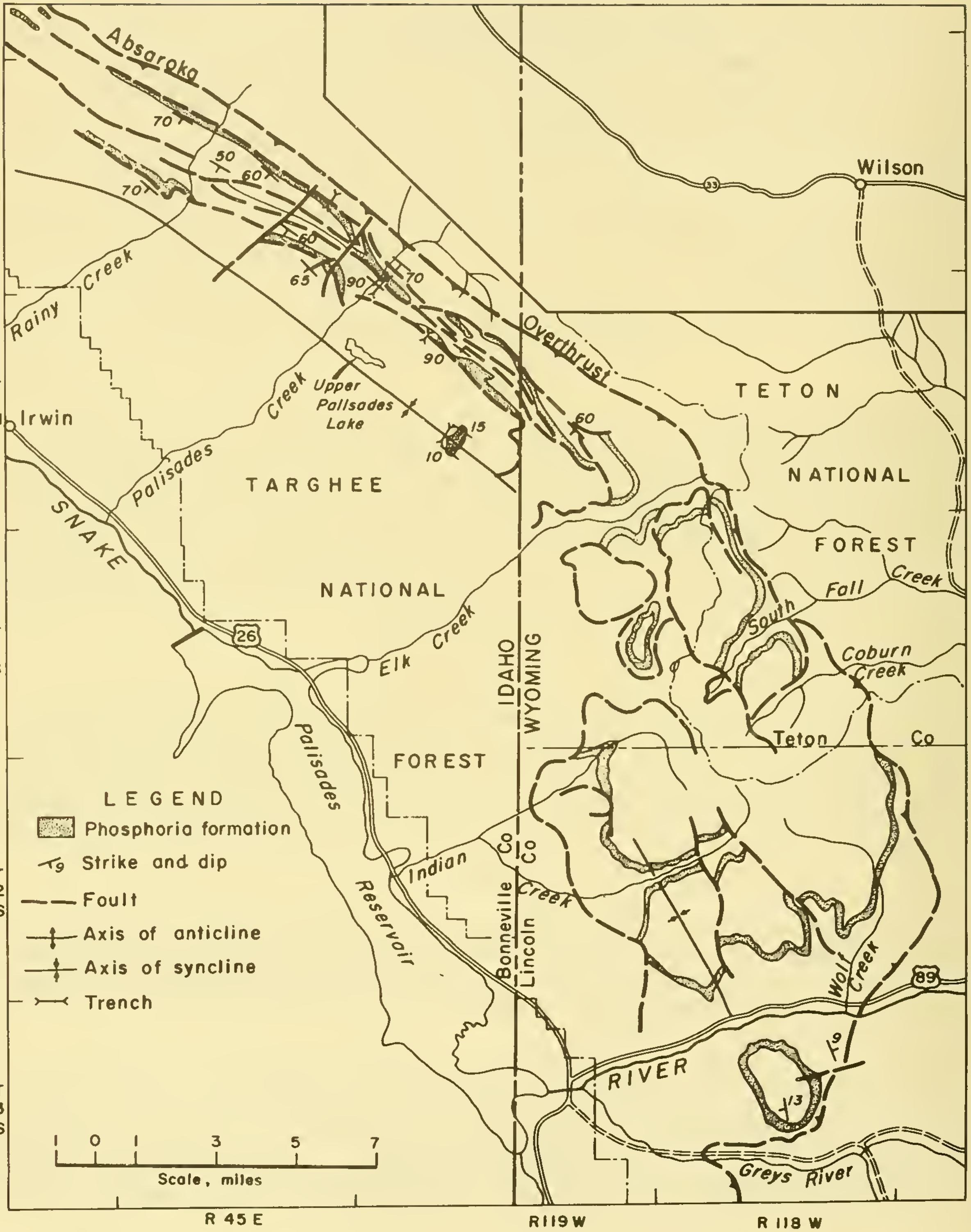

FIGURE 16. - Southern Snake River Range (20). (Modified from Gardner 1961, Jobin, Love, Osterling.)

reverse and normal faults. Although there appears to be greater lengths of undisturbed outcrops on the Wyoming side, the general broken condition of the overlying and underlying beds does not indicate any decrease in the severe structural character from that in Idaho.

There are about 80 miles of Phosphoria outcrop occurring in highly complex structural settings in the southern Snake River Range. Phosphate resources have been estimated at between 300 and 350 million short tons of +18 percent P_2O_5 rock above drainage entry. Of this total, nearly 20 million tons was considered to contain +24 percent P_2O_5 (52, p. 154). These figures are based on sections previously sampled by Gardner in the Snake River Range (21, pp. 21-24) and in the Big Hole Mountains (21, pp. 26-28). The phosphatic section in this part of the range is comparably lean (table 18). None of the trenches show any thickness greater than 3 feet containing +18 percent P_2O_5 rock. A Meade Peak outcrop on the northern breaks of the Snake River Canyon exhibited a basal bed of 3.5 feet of +18 percent category. This zone can be traced for some distance; however, access is extremely difficult.

TABLE 18. - Meade Peak sections in the southern Snake River Range[1]

Lithology	Thickness, feet	Analyses, percent				
		P_2O_5	Fe_2O_3	Al_2O_3	V_2O_3	Insoluble residue and organic matter
Trench H:						
Phosphate rock	1.5	32.3	2.0	5.4	0.03	11.0
Mudstone shale and limestone	6.3	-10	-	-	-	-
Phosphate rock	2.3	18.0	2.1	4.4	0.41	44.2
Mudstone	5.0	-10	-	-	-	-
Phosphatic shale	5.3	11.5	-	-	-	-
Phosphate rock	1.4	16.0	2.9	6.9	0.26	38.8
Limestone and siltstone	4.0	-10	-	-	-	-
Phosphate rock	0.9	15.9	1.3	4.0	0.09	44.6
Phosphate rock	2.2	24.1	1.1	6.3	0.04	29.2
Siltstone	0.3	-10	-	-	-	-
Trench G:						
Limestone and mudstone	26.3	-10	-	-	-	-
Phosphatic shale	1.0	13.7	-	-	-	-
Phosphatic shale	4.0	14.4	4.2	3.3	0.24	43.0
Limestone	1.7	-	-	-	-	-
Phosphate rock	2.0	18.6	2.4	7.2	0.10	39.5
Siltstone	4.3	-10	-	-	-	-
Trench I:						
Phosphate rock	2.3	15.7	1.8	4.5	0.38	29.7
Siltstone	0.5	-	-	-	-	-
Phosphate rock	2.4	18.4	2.3	4.9	0.33	31.5
Mudstone	1.4	-	-	-	-	-
Phosphatic siltstone	3.4	12.5	-	-	-	-
Mudstone	1.5	-	-	-	-	-
Phosphatic siltstone	1.8	13.4	-	-	-	-
Mudstone	0.9	-	-	-	-	-
Phosphate rock	1.5	21.8	3.2	9.8	0.09	21.3
Mudstone	3.5	-	-	-	-	-
Phosphate rock	1.0	15.7	2.6	8.5	0.11	40.4
Phosphate rock	2.1	27.8	-	-	0.05	15.6

[1] (21, pp. 21-24).

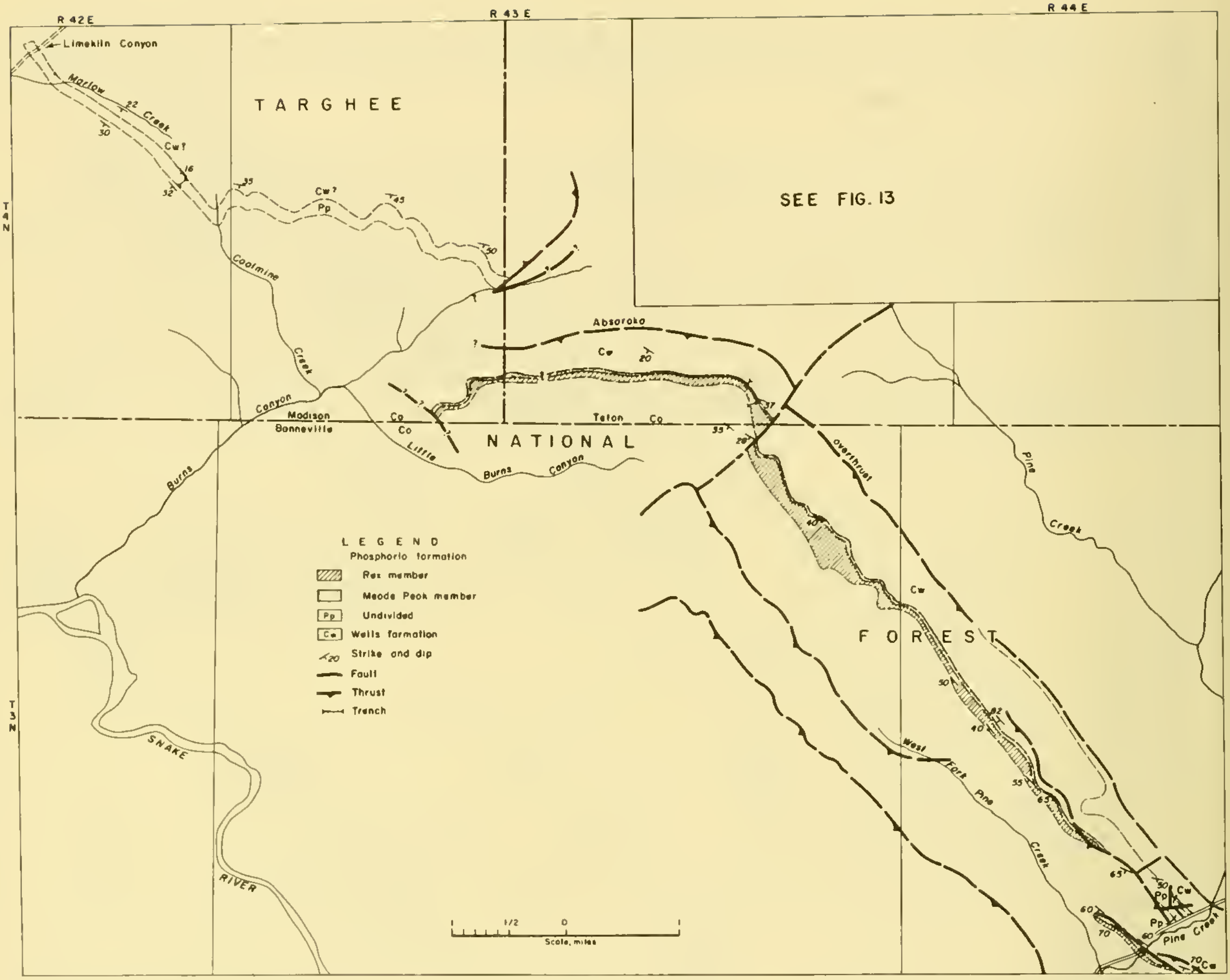

FIGURE 17. - Northwestern Snake River Range. (Modified from Albee, Staatz, Sorensen.)

Northwestern Snake River Range

General

The northwestern Snake River Range (fig. 17) is bounded on the north by the Snake River Lava plain under which all of the structures and the structure-controlled topography of the range plunges. A comparatively wide, mountainous area on the west separates the phosphate occurrences from those in the Big Hole Mountains; the Snake River forms a natural boundary on the western margin.

The area is served by two main highways (Idaho State 31 on the south border and U.S. 26N along the Snake River) and several Forest Service roads. Highway 31 cuts the two previously mentioned fault slices on the south end, and the Limekiln Canyon Forest Service road crosses a phosphate exposure just before the formation goes under the volcanics to the north.

The most practical access to the region is from the north. A branch line of the Union Pacific Railroad connects several small towns between Idaho Falls and Rexburg. Farm sidings on this line lie between 16 and 18 miles by gravel roads from the Limekiln Canyon outcrop. The nearest rail siding from the southern end is at Victor, Idaho, and involves about 15 miles of travel on a paved road over Piney Pass. A few more miles of road construction would be necessary to reach undisturbed parts of the Phosphoria formation in this area. There are a few jeep roads that approach the phosphate, but with the exception of a lease road on the north end these roads all narrow down to trails some distance from the outcrops. There are the usual forest trails in the main drainages.

While topography in the vicinity of the phosphate belt (essentially a single outcrop in this area) is not as rugged as the southern Snake River Range area, there is local relief up to about 2,000 feet. Piney Peak, elevation 9,017 feet, is the highest point in the area.

Relatively high divides exist between main drainages and the area is effectively divided into definite access routes. A route through Limekiln Canyon serves the northern area, but when the Phosphoria breaks into the Big Burns Creek drainage, there is a fairly abrupt drop of about 1,000 feet. Access to this section is limited to Burns Creek. Another high divide exists between the Burns Creek and West Pine Creek drainages to the south, and transportation between the two drainages would be prohibitive. The most convenient railhead for the Burns Creek area is at Ririe, about 25 miles by gravel and paved road from the mouth of Burns Canyon. About 10 miles of road construction would be necessary to reach the Phosphoria exposures.

Geology

Typical Snake River Range structures are predominant, although relatively long, continuous exposures of the Phosphoria formation that are not greatly affected by the major disturbed areas do occur. There are several folds, but the majority of dips are to the west and south. Near Pine Creek the disruption of beds is fairly intense, and the phosphate does not begin to show any continuity until it passes out of a faulted zone about 1.5 miles north of Pine Creek.

South of Big Burns Canyon, regional structures change the strike from northwest to nearly due west. All of the structures, including the Absaroka thrust and other fault traces, maintain a west strike until they reach the junction between Big and Little Burns Creeks. Here, the west strike is interrupted by a more north-trending structure, possibly the upper plate of the St. John thrust that has been mapped in adjacent areas.

The Absaroka fault appears to follow the landslide area on the south wall of Big Burns Canyon for some distance to the west and, like the other structures, it may also be interrupted by the St. John north-trending structure. The Absaroka fault has been mapped near the base of Temple Peak (56) and also directly across the canyon to the south where it is roughly 1,000 feet higher (1). This difference in elevation of the fault trace, as well as a similar difference in the general topography on the same formations, indicates the possibility of a normal fault along Big Burns Canyon with the upthrown block on the south.

North of Big Burns Canyon the structure has a fairly consistent northwest strike, with dips from 20° to 50° SW near the phosphate outcrops. Dips generally increase from north to south. Between Bear Trap and Jensen Canyons, where the phosphate is overlapped by volcanics, a local strike discrepancy from west to north indicates the possibility of a thrust that approaches and may even cut the Phosphoria for a short distance.

The Phosphoria formation enters the southern end of the northwestern Snake River Range in a continuation of a highly faulted zone from the south and extends over a total outcrop length of about 15 miles. There are two short fault segments exposed in road cuts at Pine Creek. This highly disturbed section extends more than a mile north of the road (Idaho Highway 31) before the formation begins to show any continuity.

North of the faulted area the Phosphoria formation is relatively unfaulted for a strike distance of approximately 4.5 miles. This outcrop dips off the west slope of the high ridge between the West and North Forks of Pine Creek. Dips range between 40° and 80° W, although most of the dips are less than 60°. The Meade Peak member is fairly well delineated on the surface, since it is a softer unit lying in a hogback-like pattern under the hard cap rock of the Rex-Franson tongues.

Near the headwaters of the West Fork of Pine Creek, the Phosphoria is offset about 1,000 feet east on the north block, and the character of the float near the fault indicates a certain amount of disruption within the Meade Peak. North of the fault the Phosphoria continues to the crest of Piney Peak without any apparent disturbance. This segment dips off the hill at about 35° to 40° SW. At Piney Peak all of the structures strike nearly due west. The Phosphoria dips steeply (45° to 60°) to the south along this trend and continues west to a point south of the junction of Big and Little Burns Creeks where it appears to be interrupted by a north striking structure. The Phosphoria has been reported as crossing Big Burns Canyon immediately to the north in one or more short fault slices, which are possibly related to the above north-striking structure.

The next trend of Phosphoria outcrop extends about 6 miles north from Big Burns Creek to Limekiln Canyon, where it is covered by volcanic rocks. There is a small area covered by volcanics between Bear Trap and Jensen Creeks, but otherwise the Phosphoria outcrop is continuous. The Meade Peak member is distinguished by the topographic break it forms. The beds dip from 20° to 50° SW, with the steepest dips in the south (fig. 18). On the west side of Argument Ridge the dips average approximately 20° on the surface. Throughout most of this area the Meade Peak member is lying just under the crest, or dipping off the hill bordering Marlow Creek. The uneroded remnant of the Franson member covering the Meade Peak member is about 20 feet thick at the crest of the hill and usually forms a dip slope up to 40 feet in thickness.

FIGURE 18. - West Dipping Meade Peak Member West of Temple Peak. Piney Peak in left background.

In 1963, the Geological Survey trenched and sampled a complete section of the Meade Peak member on the divide between Bear Trap Creek and Marlow Creek; dips in this trench ranged from nearly flat to 25° W. Another trench was excavated and sampled on the west slope of Piney Peak at about the same time.

In the Marlow Creek trench a 3-foot top bed with a P_2O_5 content of 31 percent and a 5.5- to 6-foot basal bed with a P_2O_5 content of about 24 percent were exposed. There is one zone of highly carbonaceous, phosphatic shales, 5 to 9 feet thick (crushed), comparable to the section in the Big Hole Mountains, that may run +15 percent P_2O_5. The thickness of the Meade Peak member is about 50 feet. The basal bed lies on a light buff, highly weathered calcareous mudstone (Grandeur tongue), and the upper bed is overlain by a 4-foot bed of hard phosphatic chert which grades into a cherty limestone (Franson tongue). It is difficult to obtain an accurate representation of thickness in the trench since several slippages are exposed within the middle section. The dip of the lower bed is about 14°, but the dip of the rest of the section varies from nearly flat to approximately 25° at the top.

Resources and Potential

Based on available information, the total above drainage entry resources of the northwestern part of the Snake River Range are as follows:

	Millions of short tons
Percent P_2O_5:	
+31....................	20.8
+24....................	58.7
+18....................	72.0
+10....................	87.9

These figures can also be broken down to available resources in the various access routes as shown in table 19.

TABLE 19. - Phosphate rock resources in the northwestern Snake River Range by access routes (million short tons)

Access route	Grade, percent P_2O_5							
	+31		+24		+18		+10	
	Above entry	100 feet below	Above entry	100 feet below	Above entry	100 feet below	Above entry	100 feet below
Limekiln Canyon...	2.8	0.6	8.0	1.7	9.8	2.1	11.9	2.6
Burns Creek.......	12.5	1.4	35.0	3.8	43.1	4.7	52.7	5.8
West Fork of Pine Creek............	5.5	0.7	15.7	2.0	19.1	2.5	23.3	3.0
Total.........	20.8	2.7	58.7	7.5	72.0	9.3	87.9	11.4

The most immediately available resources lie in the Limekiln Canyon access, where an estimated 150,000 short tons of +31 percent and 500,000 tons of +24 percent P_2O_5 rock are probably available by open pit methods. This area lies about 17 miles over existing gravel roads from the nearest railhead, one of the several farm sidings on a Union Pacific branch line from Rexburg to Idaho Falls. Rail shipping distance would be about 50 miles to the nearest facilities at Pocatello. The distance to the railhead is about the same through the Burns Canyon access, depending on which station is considered. There is, however, the problem of road construction (estimated 6 miles) to the nearest drainage entry point. From the Pine Creek route, the railhead lies about 13 miles on Idaho State Highway 31. Several miles of road construction would be necessary to reach the phosphate outcrops, and there is an approximate 900-foot climb over Piney Pass to reach the railroad at Victor.

SALT RIVER RANGE DISTRICT

General

The Salt River Range is a rugged, north-trending mountainous area in western Wyoming, about 45 miles long by 12 miles wide (fig. 19). Natural east and west boundaries are formed by the Greys River and Star Valleys, respectively. Topography is precipitous (fig. 20), particularly where the phosphate is exposed; local relief of 1,000 to 3,000 feet is common. The highest ridges

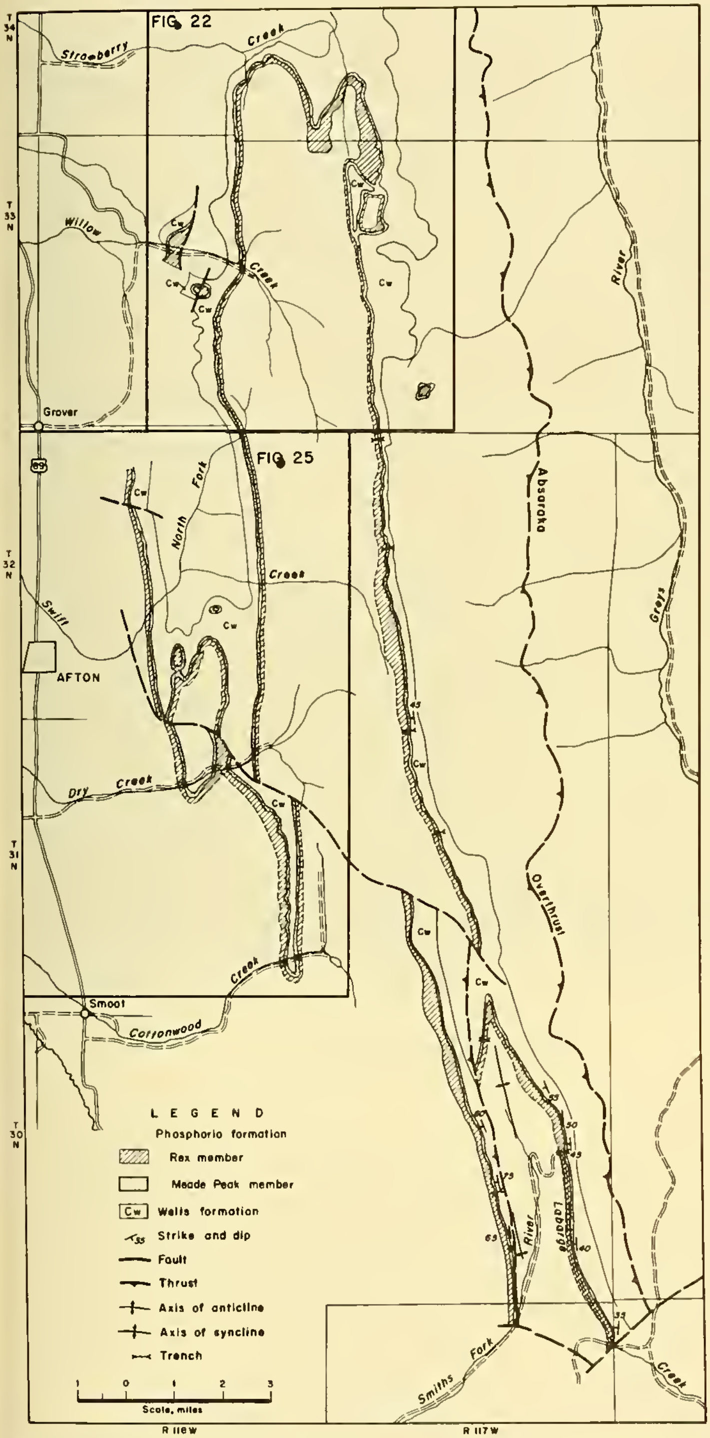

FIGURE 19. - Salt River Range District. (Modified from Allsman, Love, Mansfield, Rubey.)

and peaks are over 10,000 feet in elevation, with valleys of between 6,000 and 6,500 feet.

U.S. Highway 89 borders the Salt River Range on the west and the Greys River Forest Service road extends along the eastern border. These roads are connected by other Forest Service roads on the southern margin of the range. Some of the phosphate outcrops are crossed by good Forest Service roads from the Star Valley, but access is difficult throughout the interior area.

The nearest railheads at Border, Wyo. (Oregon Short Line), and at Ririe, Idaho (Union Pacific), are approximately 40 and 75 miles, respectively, from Afton, Wyo., the main population center in the area. All deposits lie within the boundaries of Bridger National Forest and are subject to phosphate leasing regulations. The area is covered by a single topographic sheet, the Afton Quadrangle (1:125,000), and aerial photographs are also available.

The Salt River Range has been included in several geological studies dating from the Hayden Survey of 1879; however, the only detailed geologic map of the area covers the extreme northern part of the range (46). The Geological Survey conducted a stratigraphic study of the Western phosphate field (37-38) in which the Salt River Range was included. During World War II the Bureau of Mines evaluated the vanadiferous zone of the Phosphoria formation near Afton (3). Most of the work was done where the Meade Peak crosses Dry Creek in a structure complex (fig. 21). Mansfield (34, pp. 331-349) also mapped some of the phosphate deposits in a reconnaissance study in the same vicinity.

FIGURE 20. - Typical Salt River Range Topography.

Geology

The geologic structure in this area is characterized by relatively tight folding, faulting, and steeply dipping beds with some overturning. The main fold is a large, north-trending syncline that is outlined by the surface trace of the phosphatic shales. It is accompanied by several complex structural areas such as Dry Creek where a series of folds are offset by a major cross-fault and upper Smith's Fork where an anticline is partially thrust over the adjacent syncline to the east. A large number of the Meade Peak exposures dip vertically or are slightly overturned, although there are flat-lying beds as in the upper Strawberry Creek area. North of Swift Creek the member is overturned and dips range from 30° to 40°. There is considerable faulting, with displacements ranging from less than a foot to 10 to 20 feet within the Meade Peak member. Although these small faults are not an obvious structural feature, they greatly affect the continuity of the phosphatic horizons.

FIGURE 21. - Abandoned Bureau of Mines Adit on the Vanadiferous Zone in the Meade Peak Member Along Dry Creek.

The Meade Peak phosphatic shale member is bounded on both sides by highly competent units that generally form bold outcrops. The underlying Wells formation is about 1,000 to 1,200 feet thick in the Salt River Range and forms many ledges, peaks, and ridge crests. It consists of hard quartzite and sandstone but, adjacent to the phosphatic shales, the lithology normally varies from a hard, dolomitic limestone to a hard, calcareous mudstone with some interbedded chert. The overlying Rex-Franson members range in thickness from about 80 to 150 feet.

The Meade Peak member is laterally continuous with the same horizon in the main part of the Western phosphate field in southeastern Idaho; however, it is thinner and contains less phosphate. Numerous relatively barren interbeds of siltstone, mudstone, carbonate rock, chert, and carbonaceous shale also occur. Most of them are calcareous; the phosphate-bearing zones are generally highly carbonaceous. The phosphatic series normally ranges from 35 to 60 feet and has been divided into upper and lower parts (37, p. 2). The natural division is the hard, calcareous, vanadium-bearing mudstone normally occurring from 10 to 15 feet from the top of the series. This mudstone is relatively low in phosphate content.

A single bed of +24 percent phosphate rock that may range from 4 to 7 feet is usually found in the upper part of the member. This bed is generally split by a 0.5- to 1-foot bed of barren mudstone, which may be in the center of the phosphate bed or within a few inches of the top or bottom. The remainder of the interval to the top of the vanadium zone is usually composed of low-grade, or barren, calcareous mudstone or carbonate rock.

The lower zone is somewhat thicker and contains more of a variety of grades and thicknesses in the phosphate beds. It may range from about 25 to 45 feet in thickness and may contain from one to four beds of phosphate rock, with grades of from +10 percent to +24 percent P_2O_5. These beds are generally separated by carbonate, mudstone, or shale interbeds.

Strawberry Creek-Willow Creek

The Strawberry Creek-Willow Creek area (fig. 22) contains about 25 miles of phosphate outcrops with stream-level entry points. Good gravel roads approach the outcrops on Strawberry Creek and cross the main trend on Willow Creek.

The main structure is the south-plunging nose of the previously described syncline, although there are some subsidiary folds in the upper Strawberry Creek area. A structural low occurs near the east-west line of upper Dry Canyon. The syncline and the adjacent anticline both plunge south at about 25°. Dips on the west wall of upper Strawberry Creek, south of the upper Dry Canyon line, indicate a north plunge of about 8°.

A total of six trenches were recorded by the Geological Survey in this area (37, figs. 1 and 2), and several other trenches were dug by the Bureau of Mines. Practically all of the trenches have caved and available data is limited. The Meade Peak member has been established as varying between 50 and 75 feet, including several barren carbonate and mudstone interbeds. The remaining thickness to the underlying Wells formation is taken up by the hard, calcareous mudstone of the Grandeur tongue, usually capped by a few feet of carbonate rock. The overlying Rex-Franson unit normally contains a plus 10-foot bed of hard chert adjacent to the Meade Peak member.

From the North Fork of Swift Creek to Willow Creek there is a total strike length of approximately 17,000 feet; dips are between 25° and 65° E. Average dip is about 40° to 45° E. Three trenches recorded in this outcrop length (37, p. 11) indicate a Meade Peak interval of 50 to 55 feet. Sample information and field examination indicate a basal and upper phosphate bed of 5 and 4 feet, respectively, with a phosphate content of +24 percent P_2O_5. Just above the basal bed, a zone of +18 percent P_2O_5 occurs. This bed varies from 3 to 7 feet and may be capped by a +10 percent P_2O_5 bed that has thicknesses of 0 to 12 feet in the trenches. The remainder of the section is

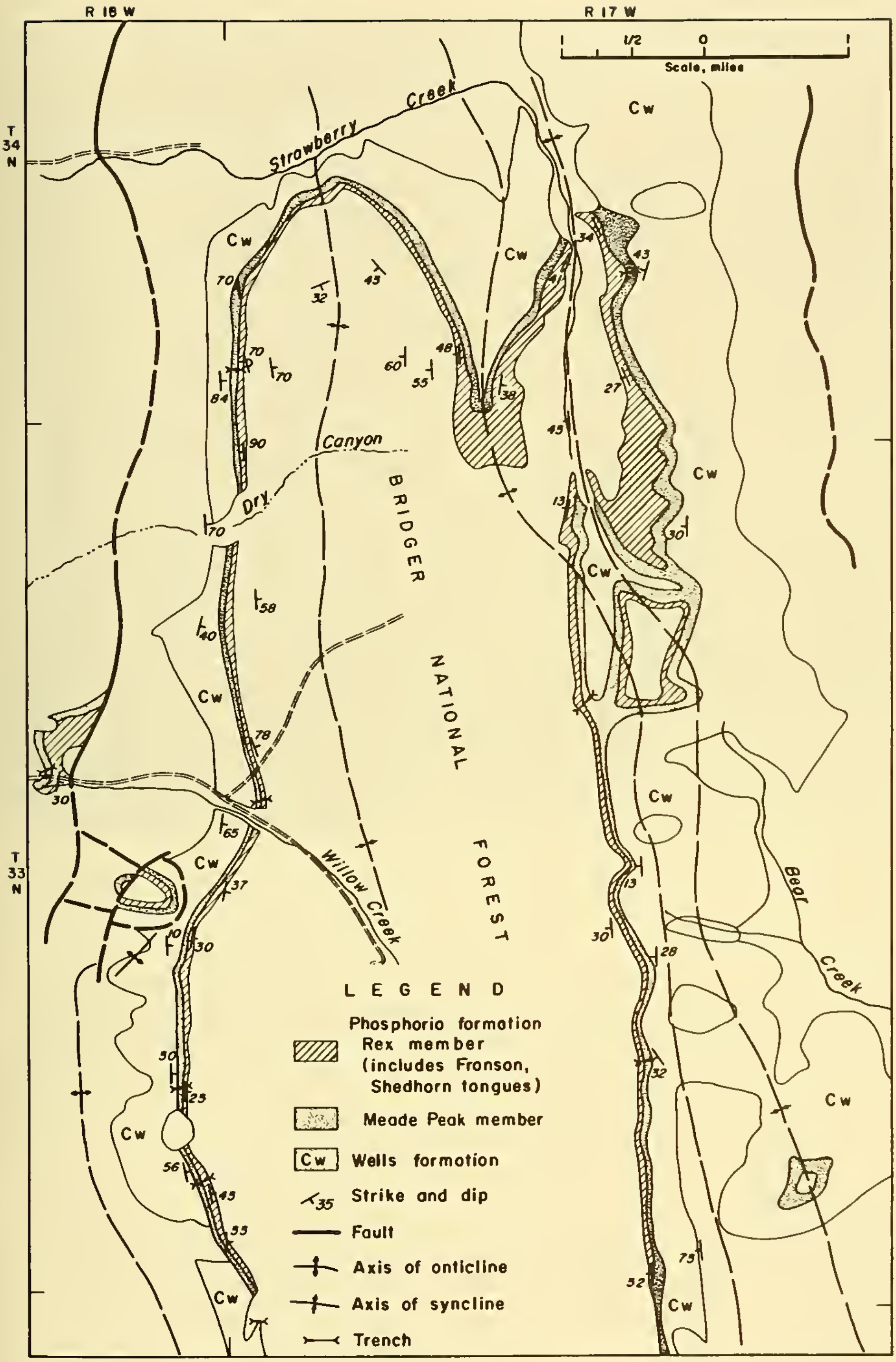

FIGURE 22. - Strawberry Creek-Willow Creek. (Modified from Rubey.)

relatively barren mudstone, 20 to 25 feet thick, containing a ± 3-foot-thick vanadiferous zone.

The Phosphoria formation continues north across Willow Creek about 10,000 feet to Dry Canyon. Dips are 70° to 80° E in the respective valleys, and 40° to 45° E on the divide. A trench at Willow Creek has a basal +24 percent P_2O_5 bed overlain by a series of mudstone beds, and 12 to 13 feet of phosphate rock ranging in grade from 12 to 17 percent P_2O_5 contained in three beds. The top phosphate bed was not exposed in this trench, but surface exposures indicate this bed is present; thickness is probably about 4 feet.

North of Dry Canyon the Phosphoria formation extends into an area of folding, dominated by a large syncline and adjacent anticline and syncline to the east. The shales dip vertically, or are overturned north of Dry Canyon until they approach the nose of the syncline where the dip changes to about 25° to 30° S. The adjacent anticline is roughly symmetrical and plunges out a

FIGURE 23. - West Dipping Meade Peak Member on the East Wall of Upper Strawberry Creek.

short distance south of upper Dry Canyon. The phosphate member crops out on both the east (fig. 23) and west wall of upper Strawberry Creek Canyon and traces a zone of relatively flat-lying structure in the headwaters area. This is a very short synclinal structure. South of McDougal Pass, the Phosphoria formation forms a continuous west-dipping outcrop (fig. 24) for about 15 miles.

Swift Creek-Cottonwood Creek

The Swift Creek-Cottonwood Creek area (fig. 25) contains about 30 miles of phosphate outcrop lying in several different structural settings. Access is relatively easy along the main drainages; Swift Creek, Dry Creek, and Cottonwood Creek. The intermediate areas, however, are difficult to reach, since relief ranges between 1,500 to 2,500 feet.

The westernmost outcrop of the Phosphoria formation is overturned for about 2.5 miles, from a short distance north of Swift Creek to where it is overlapped by the Tertiary Salt Lake formation. A crossfault offsets the beds about 500 feet west on the north block, and dips range from about 35° to 55° E at the surface. The structure appears to steepen with depth, and in Swift

FIGURE 24. - West Dipping Meade Peak Member South of McDougal Pass.

Creek Canyon the dip is 85° W. This trend continues to the south as the steep, west limb of an anticline in the complex structure between Swift Creek and Dry Creek.

Between Swift Creek and Dry Creek there is an area of phosphate outcrops that outline a series of faulted, assymmetrical anticlines and synclines. East of this tight structure the Phosphoria is exposed in a comparatively broad syncline (fig. 26). It is a distinct structure and can be traced on the surface about 4 miles to the north to Olsen Creek. Near Swift Creek and Dry Creek the structure plunges to the south.

The Phosphoria formation forms part of the steeply dipping, east flank of an anticline, complimentary to the previously mentioned syncline to the north. Beds are overturned to the east for part of the distance, and from Dry Creek to the North Fork of Swift Creek dips are essentially vertical. All of the structures between Swift Creek and Dry Creek are interrupted by a major northwest-southeast striking crossfault crossing Dry Creek near the center of the phosphate area and continuing to the south. The offset, of considerable magnitude, is to the east on the south block. One of the most obvious results of the displacement is the near-alignment of the syncline on the north block and an anticline on the south block.

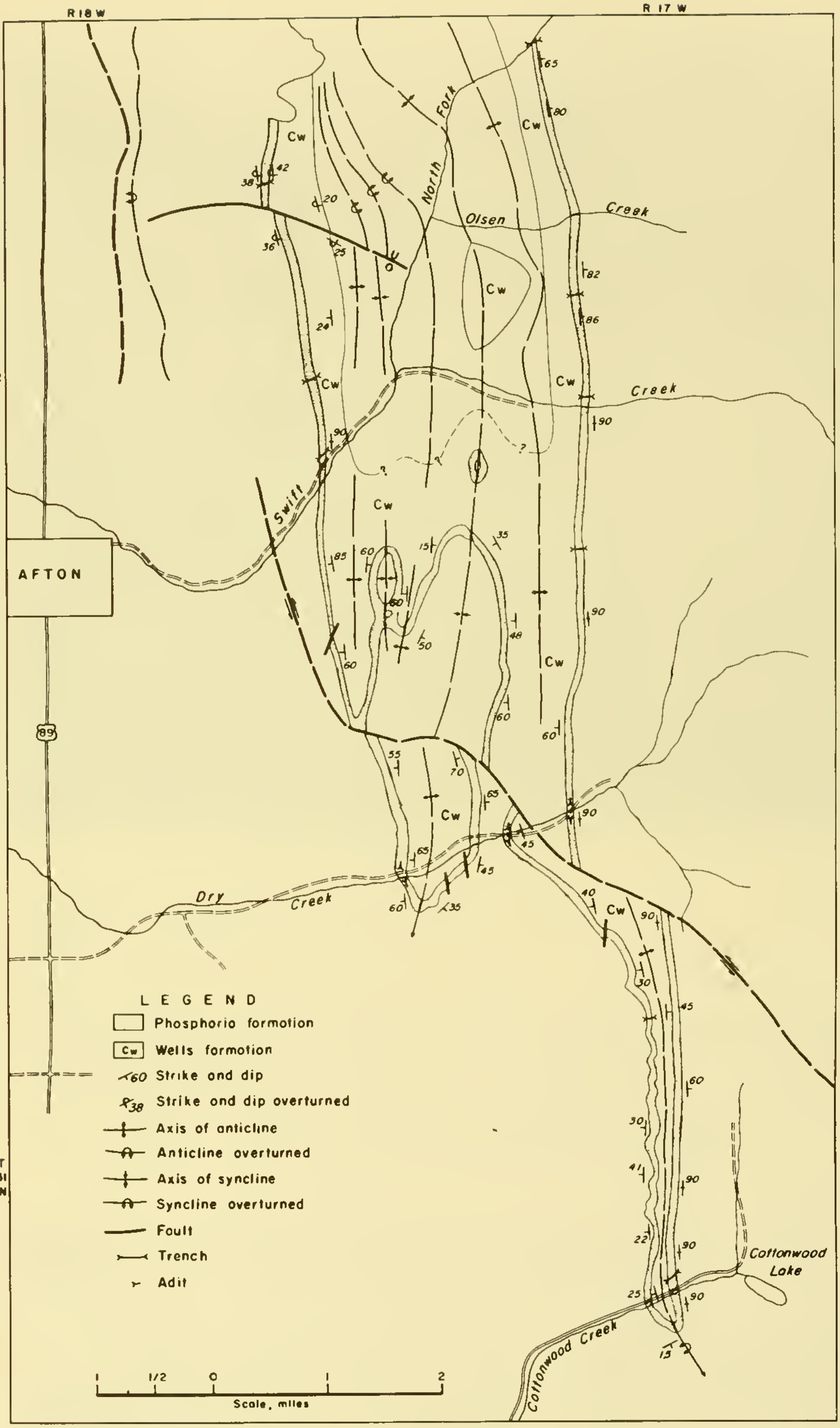

FIGURE 25. - Swift Creek-Cottonwood Creek. (Modified from Allsman, Mansfield, 1919, Rubey.)

Outcrops of the Phosphoria formation lie in two anticlines separated by a faulted syncline south of this fault. The western fold is relatively short and plunges steeply to the south, into the south wall of Dry Creek Canyon (fig. 27).

The eastern anticline exposes the Phosphoria formation on both limbs, from the Dry Creek crossfault south to Cottonwood Canyon, where the formation plunges about 15° into the hill. The dip of the west limb varies between 25° and 45° E; majority of dips are about 25° E. The east limb is nearly vertical to slightly overturned throughout most of its outcrop length, although near the Dry Creek-Cottonwood Creek divide it dips 45° to 60° W.

This area was trenched and sampled by the Geological Survey (37); however, very few analyses are available for resource estimates. Two of the trenches were opened on Swift and

FIGURE 26. - Meade Peak Member on the East Limb of the Main Syncline North of Dry Creek, Lying on Wells Formation (White).

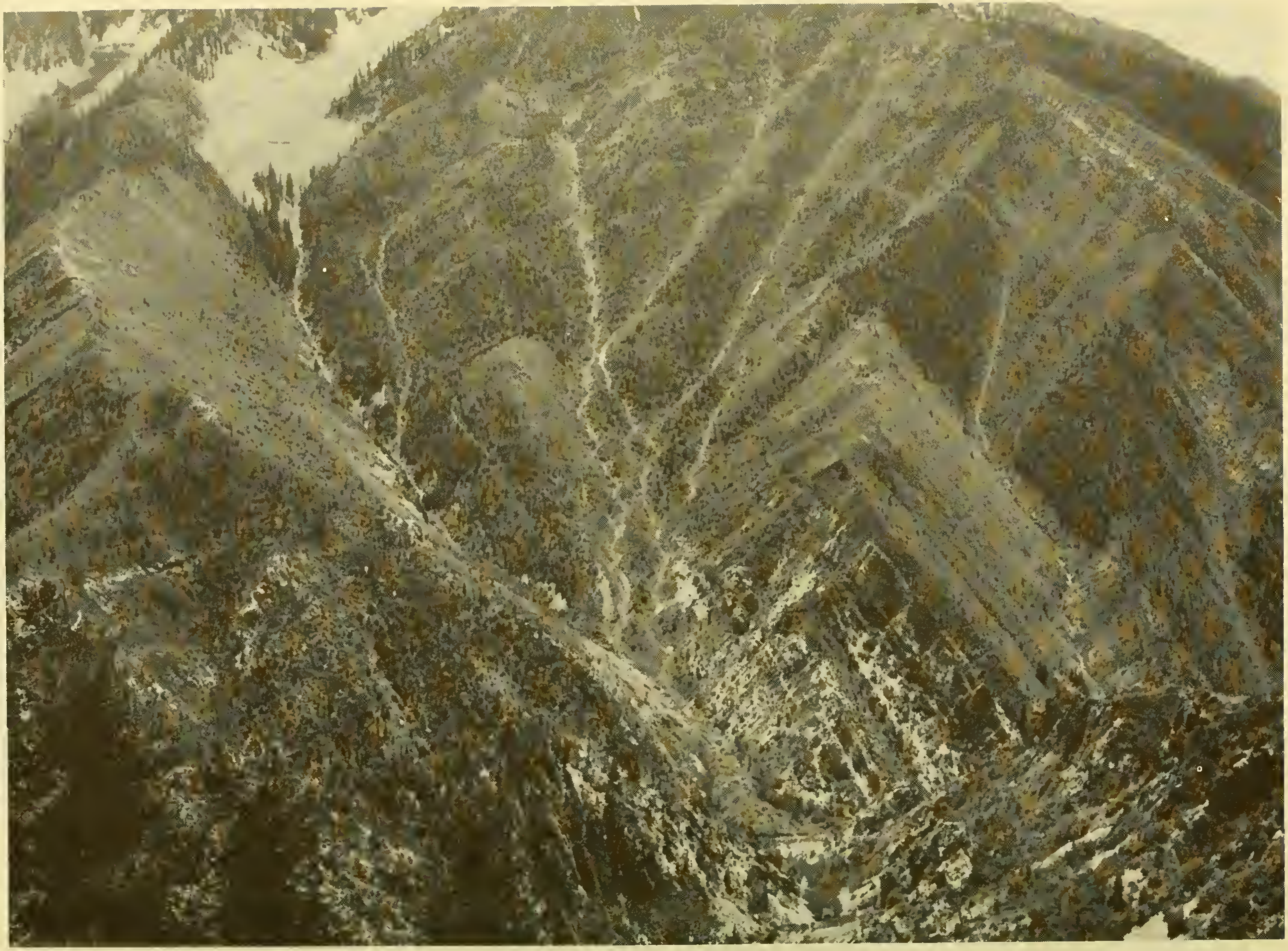

FIGURE 27. - South Plunging Anticlinal Nose on the South Wall of Dry Creek Canyon.

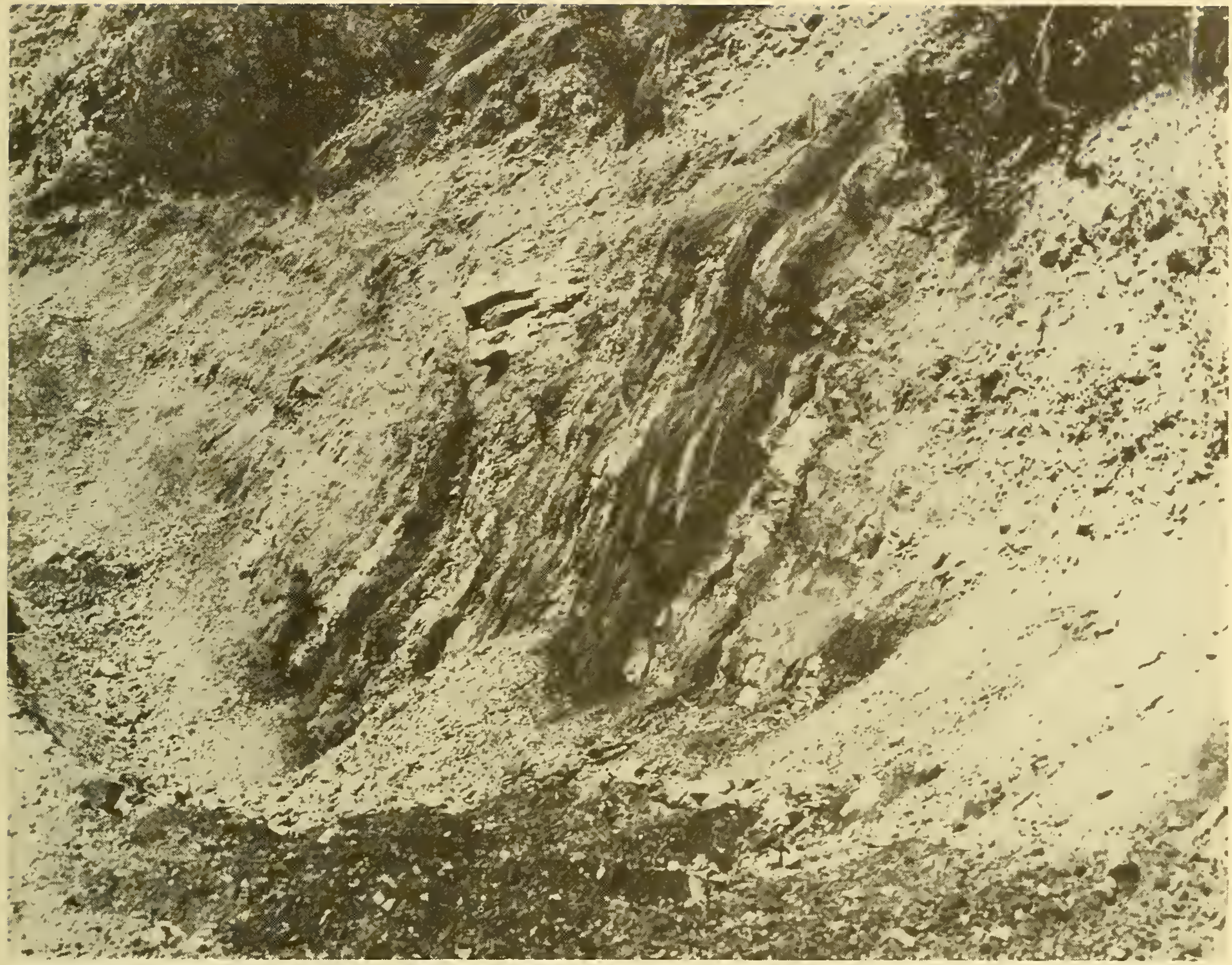

FIGURE 28. - Upper Phosphate Zone in the Meade Peak Member on Swift Creek.

Cottonwood Creeks (figs. 28 and 29) by Gas Hills Uranium Co. during their vanadium exploration. The Cottonwood Creek trench exposed top (6.5 feet) and bottom (4.0 feet) beds analyzing +30 percent P_2O_5. While the rock is highly weathered, and probably enriched, it will undoubtedly still be within the furnace-grade range at depth. South of Dry Creek, the phosphatic section is limited to these two beds with an intervening, barren section of carbonates, mudstones, and shales. The Meade Peak member, exposed in a natural outcrop on Dry Creek, contains both of these beds; the top bed is thinner than at Cottonwood Creek.

FIGURE 29. - Meade Peak Member on Cottonwood Creek.

Resources and Potential

Estimated phosphate resources in this part of the Salt River Range are shown in table 20.

TABLE 20. - Phosphate rock resources in the Salt River Range (million short tons)

Area	Grade, percent P_2O_5					
	+24		+18		+10	
	Above entry	100 feet below	Above entry	100 feet below	Above entry	100 feet below
Strawberry-Willow Creek Area....................	58.8	3.0	89.3	4.9	172.8	8.3
Swift-Cottonwood Creek Area....................	166.0	10.1	188.9	12.1	214.8	14.4
Total................	224.8	13.1	278.2	17.0	387.6	22.7

The Strawberry-Willow Creek area represents the richest deposits in the range; however, much of the area is inaccessible. The thickest section of minable beds lies near the headwaters of Strawberry Creek, requiring several miles of road construction to reach a practical entry point. Similarly, difficult road construction would be necessary to reach the outcrops in Dry Canyon and the North Fork of Swift Creek.

While the Swift-Cottonwood Creek area does not contain the rick section occurring in the northern part of the range, there appears to be a comparatively good 6- to 7-foot minable zone on both Dry Creek and Cottonwood Creek. In both places the dip is nearly vertical, and the footwall and hanging wall appear to be competent. The recently excavated trench on Swift Creek exposes the upper part of a comparatively rich section consisting of upper and lower +24 percent P_2O_5 zones and a middle +18 percent zone. All of the access roads cross outcrops of the Meade Peak member in this area.

Southern Salt River Range

The southern Salt River Range (fig. 19) contains about 19 miles of outcrops of the Phosphoria formation lying in high, rugged topography; the shales occur between 8,500 feet and 10,000 feet. The shortest access is from the west where a Forest Service road crosses the formation about 20 miles from U.S. Highway 89. Additional access to the outcrops is by steep forest trails.

In this area the Phosphoria formation lies in two predominantly west-dipping trends about equal in length. The east trend (fig. 30) dips consistently to the west, between 60° and 75°, and extends about 9 miles north from a fault in Smiths Fork River Valley to where it is faulted off by the extension of the Dry Creek fault. The outcrop lies on the upper plate of a thrust fault occurring in the Meade Peak member for a short distance on the south end.

FIGURE 30. - West Dipping Meade Peak Member on the Ridge West of the Upper Smiths Fork River Valley.

A trench near the middle of the trend exposed a thickness of approximately 50 feet of phosphatic shales showing top and bottom phosphate beds, both ranging from 4 to 5 feet in thickness. The top bed is split by a 1-foot-thick mudstone bed. The lower bed, +24 percent P_2O_5, was higher grade than the upper bed.

The eastern trend also dips to the west. On the north end, where the Phosphoria traces the nose of a sharp syncline, the west limb is faulted off at Sheep Pass. On the south, the outcrop turns to the west and crosses LaBarge Creek where it is faulted off.

The Meade Peak was trenched and sampled on the Poison Creek-LaBarge Creek divide, and the phosphatic shale interval measured 67 feet in thickness (54, pp. 37-38). The section contains a relatively rich basal section and an upper +31 percent P_2O_5 zone split by a 2-foot-thick limestone bed (table 21). A practical mining thickness on the upper zone would include the bordering low-grade beds, making a total of 5.8 feet of +24 percent P_2O_5 rock. This is assuming the middle carbonate rock could be selectively removed. The basal phosphatic zone of 7.1 feet of +24 percent P_2O_5 has competent units on either side, and could possibly be selectively mined.

TABLE 21. - Meade Peak section, Poison Creek-LaBarge Creek Divide[1]

Lithology	Thickness, feet	Analyses, percent P_2O_5
Mudstone and carbonate rock...............	12.4	1.2
Phosphatic carbonate rock.................	0.8	11.3
Phosphate rock............................	1.6	33.5
Carbonatic mudstone.......................	2.0	0.4
Phosphate rock............................	2.2	31.8
Mudstone and phosphate rock...............	1.2	11.7
Mudstone..................................	3.8	3.2
Phosphate rock and mudstone...............	1.7	19.0
Mudstone, carbonatic, phosphatic..........	24.8	4.9
Phosphate rock............................	4.7	21.7
Carbonate rock............................	4.8	6.3
Phosphate rock............................	7.1	24.6
Carbonate rock............................	6.9	0.4
Fault zone................................	12.9	([2])
Mudstone..................................	19.5	1.0
Carbonate rock............................	18.3	1.3
Phosphate rock............................	0.6	18.4

[1] (54, pp. 37-39).
[2] Repeat of adjacent beds above.

The estimated latent resources of this eastern trend are shown in table 22.

TABLE 22. - Latent phosphate rock resources in the southern Salt River Range (eastern trend) (million short tons)

Grade, percent P_2O_5	Above drainage entry	100 feet below
+24.........................	23.7	5.9
+18.........................	29.9	7.5
+10.........................	54.4	13.6

Most of the trend is dipping off the hill and the southern part is contained in a single, 5-mile-long ridge, without any crosscutting drainages, where an estimated 1.5 million tons of +24 percent P_2O_5 rock could be developed for open pit mining. This outcrop is accessible from the Forest Service road, but distances to rail facilities would undoubtedly put these resources in the latent class. It is about 50 miles to the railroad at Border (25 miles on gravel roads) and nearly 100 miles to the railroad at Kemmerer (50 miles on gravel roads).

Access to most of the outcrop on the western trend is more difficult than to the eastern trend and, therefore, the resources have been classed as latent. The Geological Survey sampled a section on this exposure (44, plate 1) showing the phosphatic zones to be thinner than in the Poison Creek area. Maximum relief on the outcrop is roughly 2,300 feet and there are considerable backs above drainage entry. Total above entry resources for this trend are estimated at about 30 million tons of +24 percent, and 50 million tons of +18 percent P_2O_5 rock, with another 2 and 3 million tons, respectively, occurring in the first 100 feet below entry level.

In addition to these latent resources in the southern part of the Salt River Range, another trend occurs on the main ridge dividing the Salt River from the Greys River drainage. This outcrop extends about 15 miles from McDougal Pass to the extension of the Dry Creek crossfault. It occurs in highly precipitous country and dips moderately to the west. The section contains several phosphate beds that can only be classed as latent (table 23; 37, plate 1).

TABLE 23. - Latent phosphate rock resources in the main ridge trend (million short tons)

Grade, percent P_2O_5	Above drainage level	100 feet below
+31	12	3
+24	23	6
+18	32	8
+10	60	12

The Salt River Range district contains enough +24 percent P_2O_5 phosphate rock to be considered a potential producer. The main detriment to development is transportation; road transport would be necessary both north (75 miles) and south (50 miles) to reach a railroad.

The Salt River Valley (Star Valley) is adaptable for the location of processing facilities. Ample power is available from Idaho Power Co. and Utah Power and Light Co., both suppliers to the area. There are also small power dams in the creeks issuing from the west side mountains, and more generating facilities are being contemplated by local interests. In view of the high carbonaceous content of the phosphate rock in this area, a kiln or reactor would undoubtedly be a part of the processing flow sheet. Fuel costs for this calcining operation would be an important factor since Star Valley is located some 50 miles from the nearest natural gas pipeline.

Gas Hills Uranium Co., Casper, Wyo., has recently applied for phosphate prospecting permits covering the vanadium claims staked in 1961. Approval of this application may lead to additional exploration in the Cottonwood Creek area.

SUBLETTE RANGE DISTRICT

General

The Sublette Range (figs. 31 and 32) extends along the southwestern border of Wyoming, approximately 25 miles in a north-south direction. It is

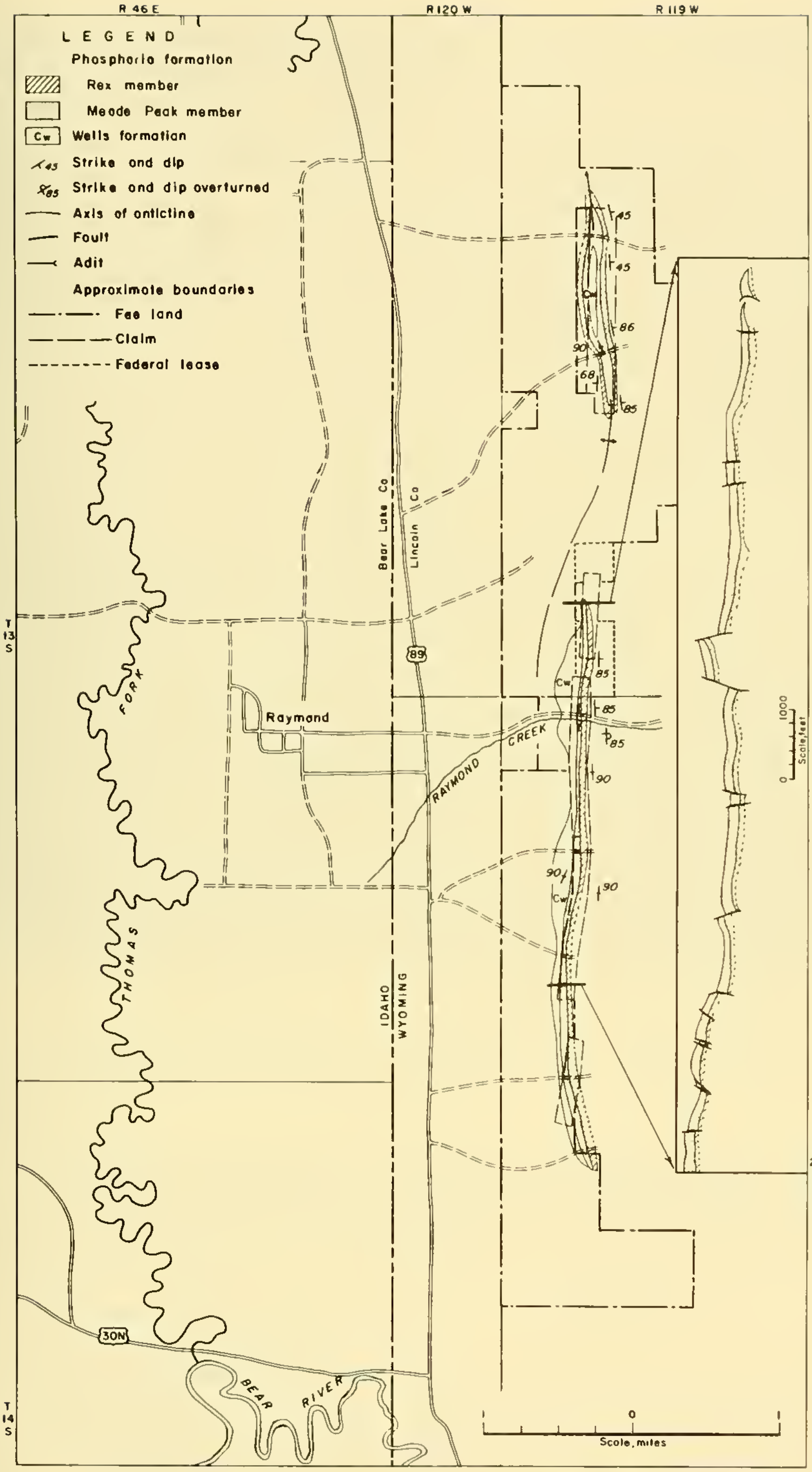

FIGURE 31. - Sublette Range District (Raymond Canyon Area). (Modified from Gale, plate 8, inset, Geological Survey unpublished preliminary map.)

continuous on the north with the Gannet Hills across Thomas Fork Creek, and on the south it ends in two isolated knobs about 1 mile east of Cokeville, Wyo. Topography is very sharp, especially on the northern end, with relief changes of about 3,200 feet. The wide Thomas Fork Valley on the west lies at an elevation of from 6,100 to 6,200 feet.

Access to the area is from U.S. Highway 89 paralleling the entire length of the range. The southern part of the area is served by the Oregon Short Line of the Union Pacific Railroad; the northernmost phosphate outcrops are about 13 miles from the nearest Oregon Short Line siding.

The area has been studied in several reconnaissance and detailed surveys by Federal and private interests. The first work followed initial discoveries in the area near the turn of the century. The most important phosphate study was done in 1909 (20, pp. 498-509). Approximately 34.5 million tons of reserves based on a 5-foot bed and a 2,000-foot depth were

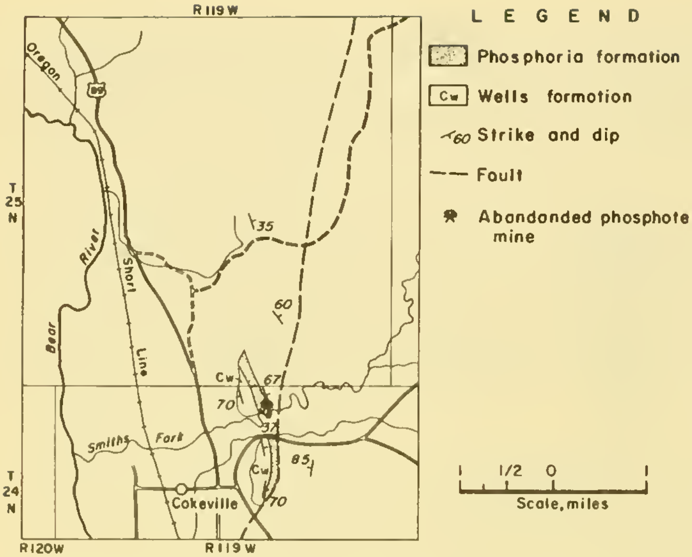

FIGURE 32. - Sublette Range District (Cokeville Area). (Modified from Gale plate 8.)

estimated. Subsequently, during World War II, the vanadium zone in the Meade Peak member was recognized (45) and several detailed surveys were made (2).

About 6,000 tons of phosphate rock were shipped from the Union Phosphate Co. mine near Cokeville before 1910. This mine (fig. 33) was reported as operating in 1926 (35, p. 296) at the rate of about 100 tons per day. The United States Phosphate Co. operated a small mine farther north in the Sublette Range in York Canyon between 1914 and 1917, but there are no available production figures.

Development operations on the vanadiferous zone were started near the end of World War II by Wyodak Coal and Mfg. Co. but were suspended because most of the vanadium was being supplied by uranium mines in Colorado. Exploration for phosphate is currently being done by Kern County Co. in the Raymond Canyon area (fig. 34). Adits originally driven along the vanadium zone by the Bureau of Mines were extended on strike to a length of about 750 feet north and 650 feet south. Samples were taken and mine-run lots of rock are being tested for possible processing techniques.

Practically all of the phosphate-bearing land in the area is covered by patented claims or is on fee land. Kern County Co., in conjunction with the Duval Corporation, controls nearly all of the patented claims in the northern part of the range (fig. 31).

Geology

The main structural feature of the area is the Sublette Range anticline that has been traced for a considerable distance both north and south of the range. The northernmost phosphate exposure traces a closed structure on this fold; however, to the south, the west limb has been faulted down beneath the valley sediments. The Phosphoria formation forms a single trend in both the Raymond Canyon and Cokeville areas. The anticline is steeply dipping on both limbs; the exposed east limb dips nearly vertically to overturned. The

FIGURE 33. - Old Workings at the Cokeville Phosphate Mine.

anticline can be recognized at Cokeville; however, the Phosphoria formation is only exposed on the east flank; the west limb is faulted and covered by valley sediments.

In addition to the major structures of the Sublette Range, small faults are relatively abundant. A detailed map of about 3.5 miles of phosphate outcrop, in the vicinity of Raymond Canyon, shows over 30 crossfaults, of which more than 20 affect the entire Meade Peak member (fig. 31, inset). The displacement on these faults is from a few feet to about 400 feet. Also, there are slipfaults that partially or completely fault out the Meade Peak over short distances.

Although some of the faults are undoubtedly the result of surface slippage or unloading, several of them persist at depth as shown in underground work. The workings at Cokeville contained at least two measurable faults about 900 feet apart in the 1,000-foot adit (20, p. 507). A somewhat similar fault density occurred in the underground workings at Raymond Canyon. On an

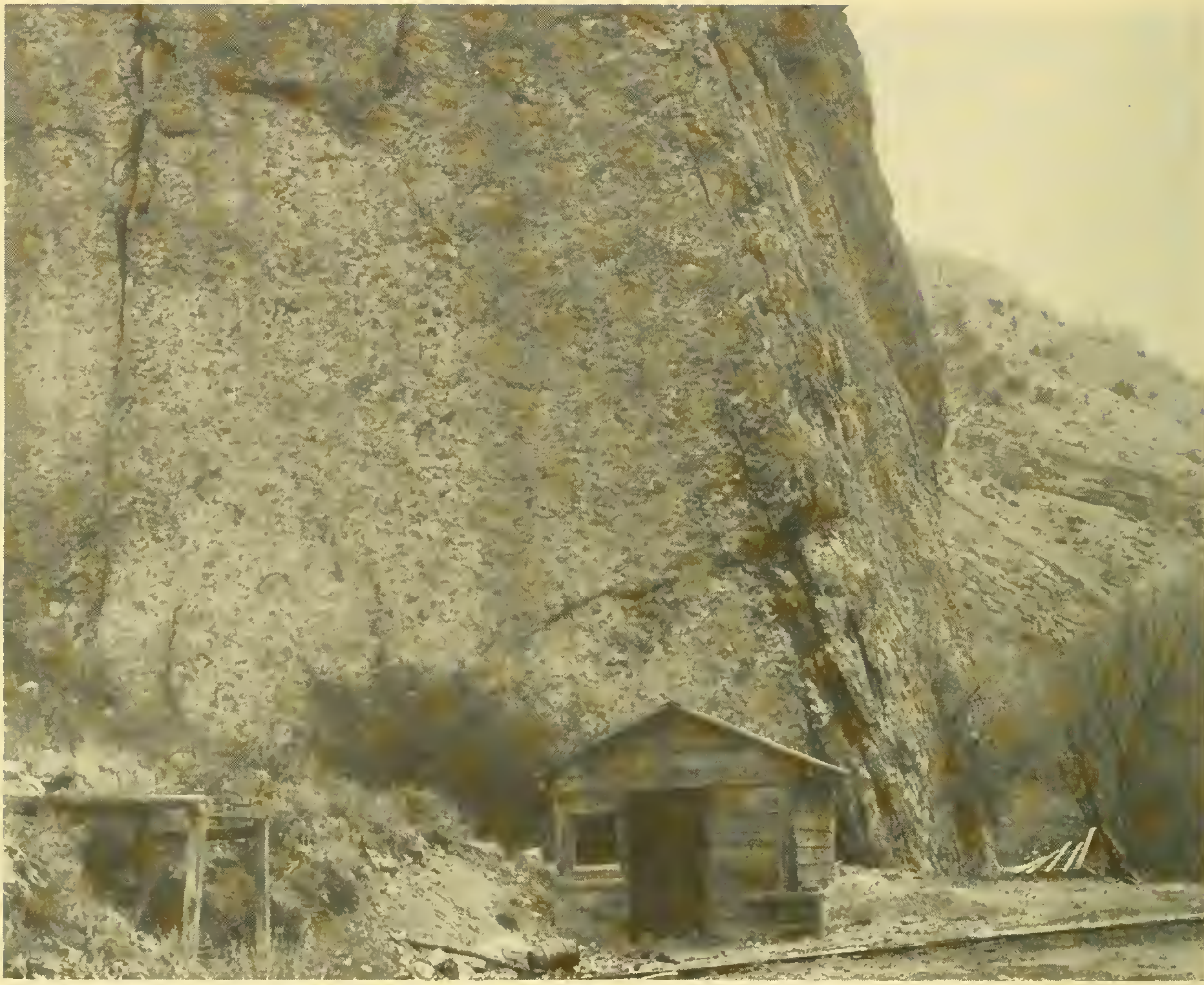

FIGURE 34. - Raymond Canyon Portal (Vertical Rex Wall in Background).

average there is about 500 feet between major crossfaults on the surface, and about 900 feet separation underground.

There has been a large amount of stratigraphic information obtained on the Meade Peak member in this area as a result of earlier phosphate mining and later exploration for vanadium and phosphate (fig. 35). The thickness of the member ranges from 125 to 150 feet, including the upper and lower mudstones. The thickest section, at Cokeville, is accounted for by a barren mudstone strata at the top that increases from about 25 feet at Coal Canyon to 50 feet at Cokeville. The sequence of beds between the upper and lower phosphate zones is actually thinner at Cokeville than in other areas. There is a lower mudstone strata at the base of the member that is consistent in thickness and ranges between 5 and 10 feet.

On the north end of the range the Meade Peak member occurs in a closed anticlinal structure and dips range from 45° to 85°; the structure flattens

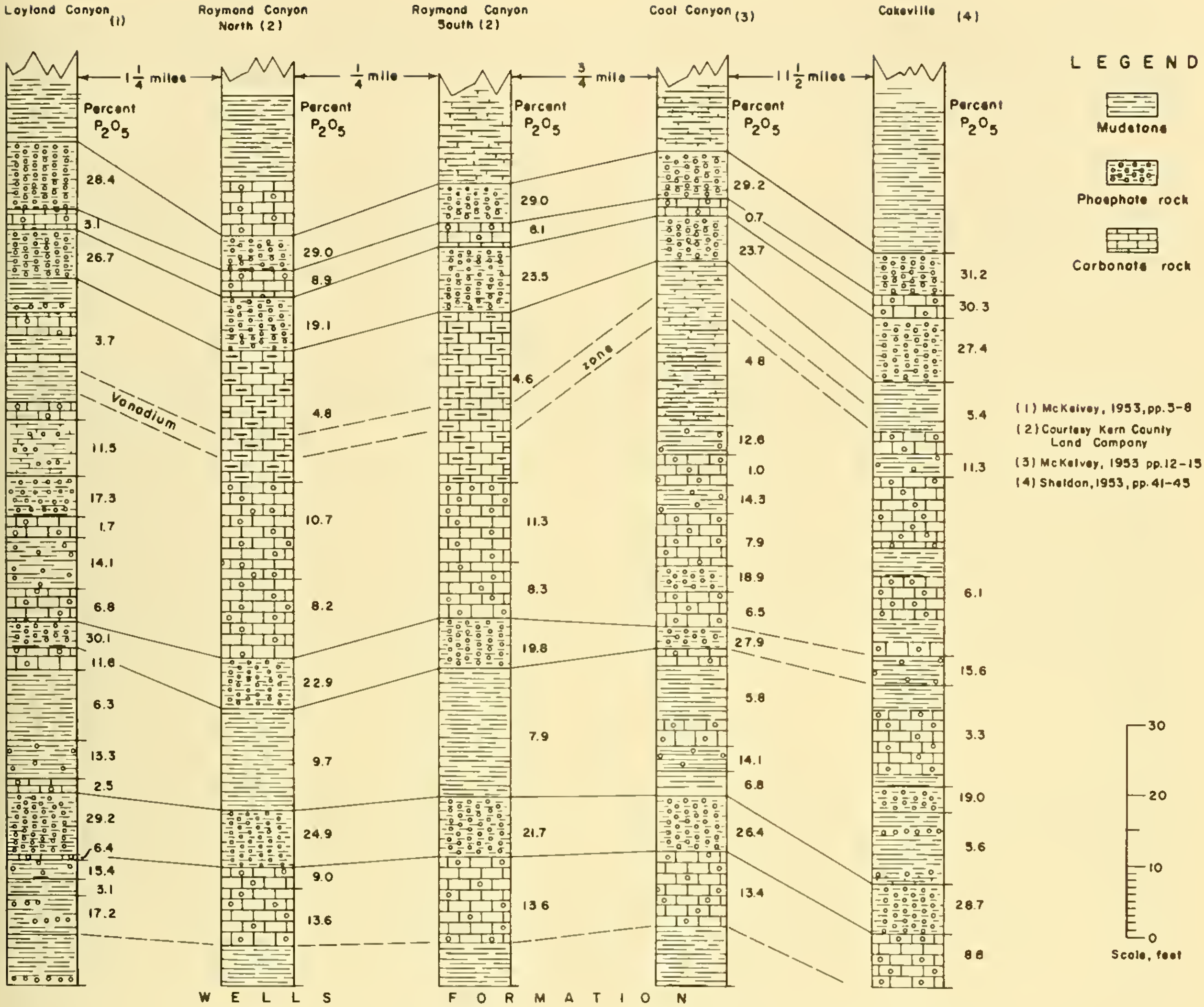

FIGURE 35. - Meade Peak Stratigraphy in the Sublette Range.

somewhat on the northern extremity. The richest section in the Sublette Range occurs on this north structure (39, pp. 5-10), although it is also the most structurally complicated area. The complexities may be inferred from the fact that the shales occur at the crest of a tight, steeply dipping anticline. A Bureau of Mines adit showed a relatively great amount of crushed and broken beds (2, p. 6).

Continuing south, the anticlinal axis veers west out into the valley and the west limb lies under a thick cover of Tertiary and Quaternary sediments. The next phosphate exposure is a single, 3.5-mile outcrop on the east limb of the Sublette anticline. It dips nearly vertically and is overlapped on both ends by younger beds as it trends down to lower elevations.

Three sections have been sampled on this trend (fig. 35). Two are in underground crosscuts about 1,000 feet north and south of Raymond Canyon and the other is a hand trench in Coal Canyon (39, pp. 11-15). These sections show a decreasing thickness in the member to the south as the middle phosphate zones begin to thin out. The upper main bed in the lower part of the series thins to less than three feet at Coal Canyon, and the lower grade zone above this pinches out between the south crosscut at Raymond Canyon and Coal Canyon.

The Meade Peak member in Coal Canyon was studied in detail by the Geological Survey, with emphasis on the mineralogical and chemical characteristics of the phosphate rock. In this study each sample horizon was quantitatively analyzed for several elements. Table 24 shows weighted averages of this data for the four main phosphatic zones and the vanadium zone.

TABLE 24. - Weighted analyses of phosphate beds and vanadium zone in Coal Canyon[1]

Thickness, feet	Lower phosphatic horizon		Vanadium zone	Upper phosphatic horizon	
	Lower bed	Upper bed	3.5	Lower bed	Upper bed
	7.8	2.8		6.4	6.7
Constituents, percent:					
P_2O_5	26.4	27.9	2.3	23.7	29.2
CaO	39.9	41.9	8.4	37.9	43.4
SiO_2	14.1	9.8	44.9	19.8	11.4
V_2O_5	0.16	0.17	0.67	.06	0.15
F	2.5	3.1	0.34	2.5	3.1
Fe_2O_3	0.9	1.1	3.8	1.6	0.9
Al_2O_3	1.7	1.7	8.8	3.0	1.9
MgO	1.0	0.52	2.2	0.36	0.28
CO_2	3.9	2.6	5.7	3.8	2.3
TiO_2	0.13	0.12	0.32	0.23	0.12
K_2O	1.19	0.64	2.5	0.92	0.81
Na_2O	0.87	1.2	1.2	1.1	1.00
S (as SO_3)	3.0	3.3	9.6	2.4	3.0
H_2O	1.2	1.2	0.46	0.78	0.91
AI[2]	13.2	7.8	55.8	20.4	9.3
LOI[3]	9.2	11.6	18.9	9.2	7.2
eU[4]	0.0130	0.0131	0.004	0.006	0.020
U	0.0111	0.0101	0.001	0.007	0.018
Minerals, percent:					
Carbonate fluorapatite[5]	68.6	72.3	6.0	61.6	75.9
Dolomite	4.7	2.4	10.1	1.7	1.3
Calcite	0.7	1.3	2.4	4.3	0.9

[1] (24, pp. 77-79).
[2] Acid insoluble.
[3] Loss on ignition.
[4] Equivalent uranium determined by radioactivity analysis.
[5] Obtained by multiplying P_2O_5 percent by 2.6.

The next outcrop of the Phosphoria appears on Cokeville and Signal Buttes east of Cokeville; the Meade Peak member is exposed only on the Cokeville Butte. The Meade Peak is apparently faulted out somewhere in the Smiths Fork Valley and trenches on Signal Butte have exposed only broken remnants or gouge of the phosphatic shales.

Hand trenches on Cokeville Butte exposed a section that includes a single bed at the base and the two beds higher in the section. The intervening part of the section has diminished in phosphate content at this point, to where no beds of greater than 10 percent P_2O_5 can be defined, although considerable thicknesses contain just below 10 percent P_2O_5 (52, pp. 41-45)

The Sublette Range probably contains the richest phosphatic section in Wyoming. Thicknesses range from 91 feet at Cokeville to 110 feet at Layland Canyon on the north anticline. Similarly, the phosphate content of the entire section increases from 11.4 percent P_2O_5 at Cokeville to 14.2 percent P_2O_5 in Layland Canyon.

Samples from both underground and surface workings offer a comparison between the effect of surface enrichment by weathering on the phosphate member and unweathered phosphate rock at depth. On the basis of the trend of total phosphate content from Coal Canyon to Layland Canyon, the Raymond Canyon cross-cut samples fall below the expected total phosphate content by about 8 to 10 percent. A sample taken at the surface, assaying 30 percent P_2O_5, would probably contain between 27 and 27.6 percent P_2O_5 in an unweathered section in the same bed at depth.

This comparison is made over about 3.5 miles and may not be entirely representative, since the phosphate is known to vary in grade over shorter distances in other areas. North of Raymond Canyon, the effect of weathering is more pronounced. The upper phosphate zone was sampled on the surface in an earlier survey (20, plate 8) and more recently a similar section was sampled underground. The difference in total phosphate content between these two samples is about 15 percent P_2O_5.

Resources and Potential

The Sublette Range district contains about 6 miles of steeply dipping phosphate outcrop. Total resources above and 100 feet below drainage entry in the district are shown in table 25. These figures are based on in-place rock and do not consider possible faulting complications or mining loss.

TABLE 25. - Phosphate rock resources in the Sublette Range (million short tons)

Grade, percent P_2O_5	Above drainage entry	100 feet below
+24	26.4	5.8
+18	41.7	7.9
+10	146.8	27.5

The Sublette Range area rates relatively high for future development in Wyoming. Initial exploration has already been undertaken and the region is well located for both transportation facilities and market areas. At least two of the four minable beds in the member could be extracted by underground methods with few problems of ground support. It appears that development is dependent upon favorable market conditions rather than problems of mining and processing.

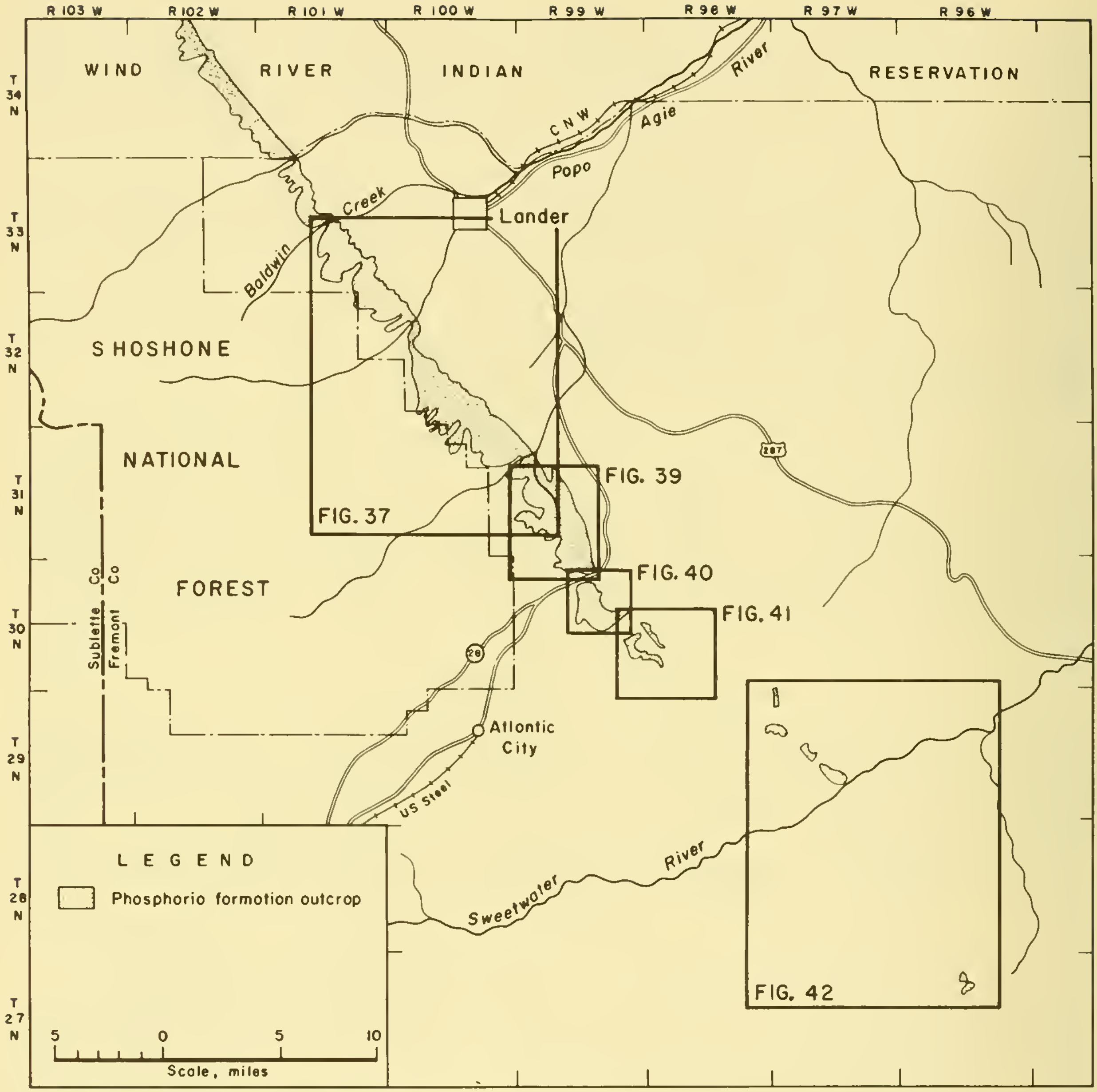

FIGURE 36. - Southeastern Wind River Range District.

SOUTHEASTERN WIND RIVER RANGE DISTRICT

General

The Wind River Range extends across western Wyoming in a northwesterly direction for over 100 miles. The only area where potential phosphate rock resources occur is in the southeastern part (fig. 36). To the south, topography flattens out into the Great Divide Basin and in the north, it extends to Yellowstone National Park. The range is flanked on the northwest by the

Gros Ventre and Bighorn Ranges. The interior of the district is a very rugged area of granites and metasediments, with mountain peaks ranging up to 13,000 feet. The fringes of the range display a hogback type of topography with steep slopes and mountainous peaks in the interior, grading to gentler slopes toward the surrounding basins.

Wyoming State Highway 28 crosses the south end of the district; U.S. Highway 89 parallels the west side and U.S. Highway 287 parallels the east side. Several secondary roads cross surface exposures of the Phosphoria formation on the northeast flank of the range. Lander and Riverton are the nearest population centers. The Chicago and Northwestern Railroad terminates at Lander, about 6 miles from the nearest phosphate deposits. A recently constructed branch line of the Union Pacific Railroad ends at Atlantic City and connects with the main line at Rock Springs. The lands in the district include the Shoshone and Bridger National Forests, the Wind River Indian Reservation, and State and private lands. Phosphate leases have to be negotiated with the tribal council, or acquired according to Federal and State lease regulations, depending on the status of the land ownership.

In 1924 the upper and lower phosphate zones were mapped over a large area extending south from Bull Lake to the Sweetwater River and including the Sheep Mountain anticline. Several sections were measured and representative samples analyzed, but no estimates of resources were made (13). From 1947 to 1950 the phosphate resources in the Lander-Twin Creek area were studied by the Wyoming Geological Survey (28) and the Bureau of Mines (29). The Bureau of Mines work was confined to the Twin Creek area and included studies of the feasibility of mining and processing. It led to further studies in processing and beneficiation (15). This has been of particular and continuing interest since it contains the richest deposits in the range and is conveniently located to railroad transportation.

Geology

The Wind River Range represents an extensive uplift area containing a granitic and metasedimentary core with an area of structural influence of about 2,500 square miles. Near the granitic contact dips are fairly steep but flatten gradually to a few degrees before the beds become covered by overlapping younger sediments or enter the gentle structural folding in the Wind River Basin. On the southwest side of the range, the slopes rise abruptly from Tertiary sediments and glacial deposits. Here dips are steeper and less consistent.

Along the northeastern side of the Wind River Range the beds of the Phosphoria formation dip from 5° to 20° NE and strike northwest. Near Red Canyon there is a reversal in attitude, and the formation crops out on the steep, dipping west limb and more gentle-dipping east limb of an anticline. Approximately 10 miles to the southeast, the Phosphoria formation occurs in the Sheep Mountain anticline, a relatively gentle structure that has been faulted to some extent. South of Sheep Mountain, the formations are offset by a major fault that also cuts off the Sheep Mountain anticline. Several small normal faults occur near Willow Creek, but they have not crushed or disturbed the bedding to any great extent.

The Phosphoria formation is easily traced on the surface because of the distinctive enclosing units. The Tensleep formation, on the bottom, is composed of fine- to medium-grained sandstone with a maximum thickness of 450 feet (13, p. 10). The sandstones form prominent vertical cliffs deeply incised by streams; the soil cover supports tree growth in contrast to the range grass and sagebrush found over the Phosphoria. The Phosphoria formation is overlain by about 50 to 100 feet of sandy shales of the Dinwoody formation.

The Chugwater red beds, varying in thickness up to 1,000 feet in the north to 1,500 feet near Lander, overlie the Dinwoody formation. These red beds cover an extensive area on the flat slopes of the northeast flank of the range, and provide marker beds for the Phosphoria-Dinwoody interval.

The thickness of the Phosphoria formation varies from a little less than 200 feet to about 350 feet along the eastern front of the range. The formation was originally divided into 3 zones based on the physical characteristics. The upper and lower zones are primarily carbonates, although they contain appreciable amounts of calcareous sandstone and mudstone; the middle zone is a softer and more shaley unit. Chert interbeds and cherty zones occur throughout the formation, becoming more definable as beds in the middle zone (13, pp. 11-13). A later study defined the lithology of the formation in more detail and the phosphate zones were considered as the upper and lower beds, separated by 60 to 150 feet of carbonates, cherts, shales, and sandstones (28, pp. 7-9). Still later, the zones were defined as occurring in the Meade Peak and Retort members of the Phosphoria formation (38, plate 3). These zones show much variation in grade, both locally and regionally.

The richest beds in the Wind River Range lie in the Lander-Twin Creek area; grade decreases laterally from this vicinity. In the Twin Creek area the Meade Peak member usually contains the richest phosphate beds but, in other areas, grade decreases more sharply than in the Retort member. The Meade Peak member is barely perceptible or completely missing in the Sheep Mountain area and near the Sweetwater River (13, pp. 33-34). In the northern part of the district the Retort member becomes more prominent than the Meade Peak member. North of Baldwin Creek, both members are too thin to be considered as potential resources.

Baldwin Creek-Cherry Creek

The area from Baldwin Creek south to Cherry Creek (fig. 37) was studied by King in 1947 (28) with a resource evaluation similar to this work; a minimum bed thickness of 3 feet and the estimation of resources above and 100 feet below drainage entry. The Phosphoria formation crops out for a strike distance of about 15 miles in a series of "flat irons," separated by deeply incised streams. Dips are from 8° to 20° NE; however, the majority are from 8° to 12° NE.

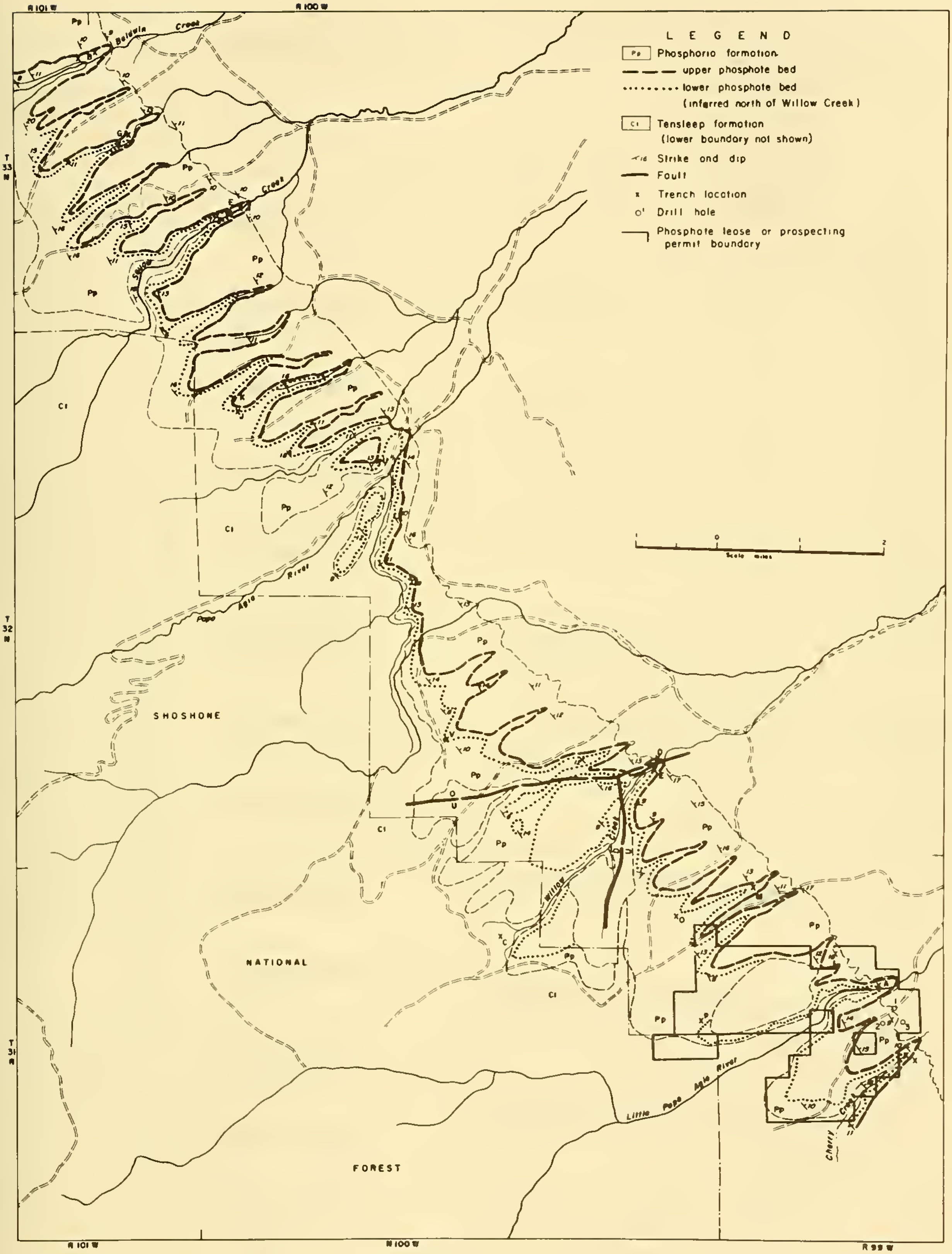

FIGURE 37. - Baldwin Creek-Cherry Creek (14). (Modified from Condit, King, R.H., King, W.H.)

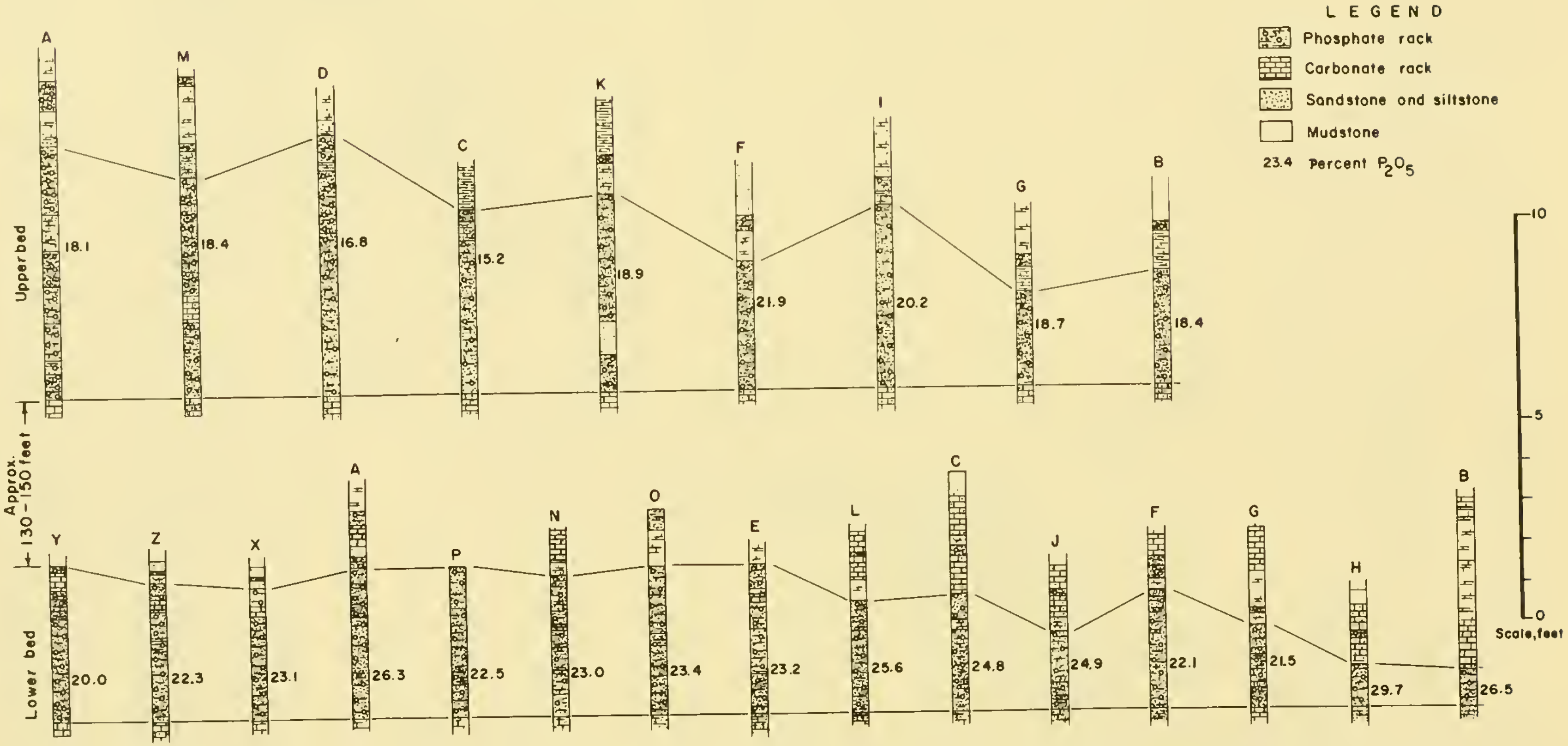

FIGURE 38. - Detailed Sections of the Lower and Upper Phosphate Beds in the Baldwin Creek-Cherry Creek Area. (Modified from King, R. H., figs. 4 and 5.)

Detailed sampling information on this trend is available (fig. 38), and the limits of the various thicknesses have been well defined. The lower zone is richer, although the lateral extent of occurrences of a +3-foot bed is less than the upper bed (28, figs 1 and 2). Estimated resources from this survey are shown in table 26.

TABLE 26. - Estimated phosphate rock resources, Cherry Creek to Baldwin Creek[1]

	Analyses, percent P_2O_5	Bed thickness, feet	Tonnages, short tons	
			Above drainage entry	100 feet below
Retort	20.2	3.8	6,700,000	300,000
	20.2	3.6	6,250,000	900,000
	19.7	4.2	2,325,000	400,000
	19.3	4.7	4,475,000	875,000
	18.8	4.8	1,850,000	225,000
	18.3	4.7	4,600,000	525,000
	18.3	5.6	8,425,000	1,050,000
	18.3	6.0	7,825,000	1,275,000
	18.3	5.8	4,125,000	1,050,000
	17.4	5.8	16,950,000	1,800,000
	17.0	4.6	1,625,000	325,000
	17.0	6.3	1,825,000	425,000
	16.5	5.8	8,400,000	1,075,000
	16.1	5.6	8,325,000	900,000
	15.6	5.0	16,700,000	2,700,000
	15.1	4.5	775,000	-
Total Retort	-	-	101,175,000	13,825,000
Meade Peak	24.3	3.5	8,340,000	780,000
	24.3	3.7	7,660,000	730,000
	23.9	3.7	5,280,000	830,000
	23.4	3.6	8,610,000	1,440,000
Total Meade Peak	-	-	29,890,000	3,780,000
Total Retort and Meade Peak	-	-	131,065,000	17,605,000

[1] (28, pp. 79-80).

Red Canyon

North of the Twin Creek-Red Creek divide, the P_2O_5 content decreases as the Phosphoria formation extends into the Little Popo Agie drainage (fig. 39). The regional northeast dip of the formations is interrupted by a doubly plunging, assymmetrical anticline bounded on the west and east by Barrett and Red Canyon Creeks, respectively. This structure plunges to the south much more sharply than to the north. The east limb dips from 20° to 30° NE and the west limb from 50° to 60° SW. Barrett Creek traces the trough of the complimentary syncline. On the west limb of this structure the attitude of the strata conforms to the regional pattern with dips of 8° to 10° NE.

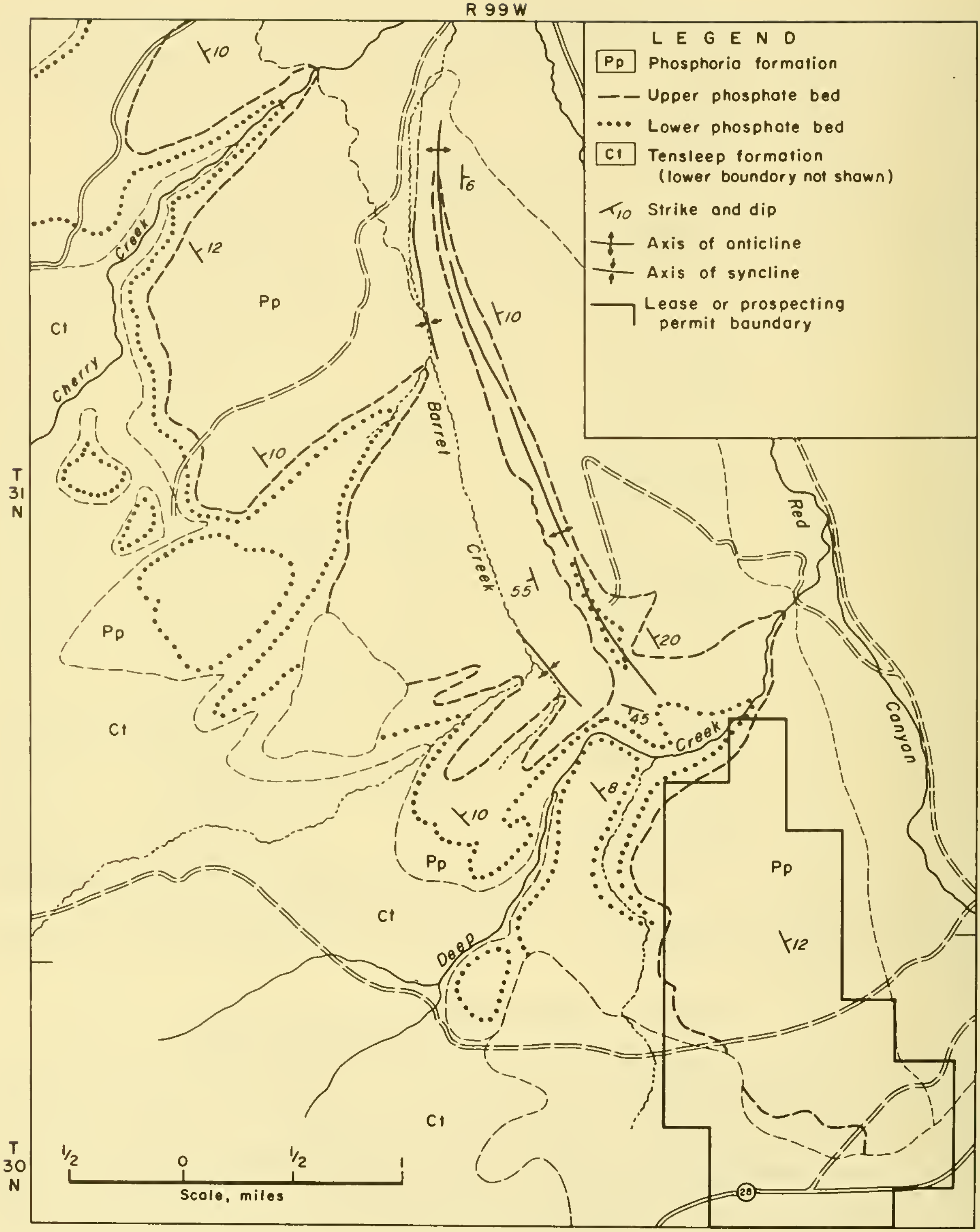

FIGURE 39. - Red Canyon. (Modified from Condit, King, R. H., Mackay.)

Both the lower and upper beds were sampled by Condit (13, plate 3), and in 1947 the lower bed was sampled in three places (28, pp. 73-75). The southernmost sample in the lower bed was taken by Condit on Deep Creek. A little over 4 feet of phosphate rock was exposed at this location; a 2-foot bed analyzed about 23 percent P_2O_5. The same survey exposed about 1 foot of phosphate rock in the upper bed on the ridge between Deep and Barrett Creeks. In upper Red Canyon Creek, a 3.5-foot bed containing about 17 percent P_2O_5 was exposed (13, plate 3).

In addition, the Bureau of Mines explored the "flat iron" area south of the Little Popo Agie River (Macfie block) with three drill holes (table 24; 29, p. 8). This block lies between Cherry Creek and the Little Popo Agie River and within the area included in table 26.

TABLE 27. - Drilling results on the Macfie block

Corehole	From	To	Thickness, feet	Analyses, percent			
				P_2O_5	CaO	SiO_2	F
1................................	261.2	266.0	4.8	25.85	42.4	12.2	3.0
2................................	261.5	265.4	3.9	25.35	41.1	14.1	3.1
2................................	260.4	265.4	5.0	22.60	38.0	16.6	2.8
3................................	273.3	276.35	3.05	26.60	42.4	12.4	3.1
3................................	271.2	276.35	5.15	20.87	-	-	-

The Bureau of Mines survey exposed a lower 4-foot bed with a 21 percent P_2O_5 content on both Barrett Creek and Deep Creek. A similar bed, with the same P_2O_5 content, was exposed in a trench farther to the north on Cherry Creek. The four trenches in the Meade Peak member establish a 4-foot thickness of beneficiation-grade rock in this area. About 22.3 million tons of +18 percent P_2O_5 rock would be available above entry level and 4.1 million tons to 100 feet below entry level.

The resources of the phosphate rock in this area are estimated only for the Meade Peak member since the upper zone apparently contains only a relatively thin low-grade bed. The total bed area of the upper zone is sizable; approximately 90 million square feet above drainage level with between 10 and 15 million square feet for every 100 feet of depth below drainage. This is approximately 7 million tons of rock for every foot of bed thickness.

Twin Creek-Tweed Creek

The Twin Creek area (fig. 40) was explored by the Bureau of Mines, and a relatively small quantity of ore in the lower bed was blocked out (29). A shaft was sunk to obtain a 50-ton sample of phosphate rock for process studies by the University of Wyoming (15).

Diamond drill holes established an average dip of 8° NE in the exploration area, and throughout the entire Twin Creek area dips do not exceed 12° NE. In the drill area, the thickness of the lower phosphate bed is between 7.5 and 8.5 feet (table 28). This is probably the richest phosphate area in the Wind River Range; other data indicate decreases in grade and thickness both to the north and south. The lower bed was sampled on Tweed Creek and the upper bed was sampled in a small anticlinal crest about 1.5 miles to the west (13, plate 3). Both beds are about 4 feet thick; the lower bed averages 27.6 percent P_2O_5 compared with 20.6 percent P_2O_5 for the upper bed.

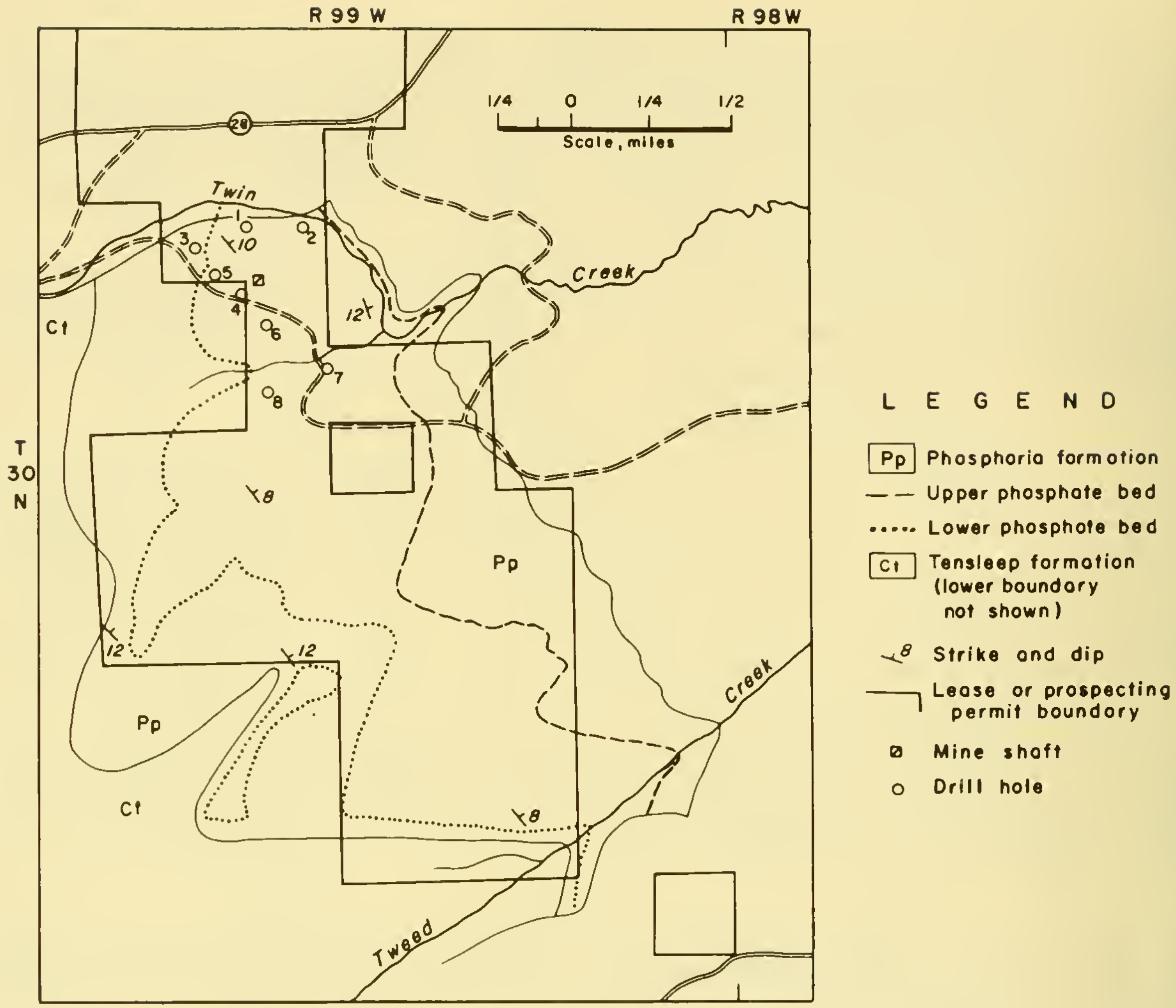

FIGURE 40. - Twin Creek-Tweed Creek. (Modified from Condit, Gooldy, King, W.H., and Mackay.)

TABLE 28. - Drilling results in the Twin Creek area[1]

Hole	From	To	Thickness, feet	Analyses, percent			
				P_2O_5	CaO	SiO_2	F
1	86	92	6.0	25.1	39.2	15.3	2.8
1	84	92	8.0	24.6	39.7	13.5	2.8
2	182.4	188	5.6	23.2	40.4	14.8	2.0
2	180.3	188	7.7	22.3	40.5	13.1	2.9
4	45.0	51.1	6.1	23.5	39.9	14.3	2.1
4	43.5	51.1	7.6	22.6	39.9	12.6	2.2
6	50.8	57.1	6.4	22.7	39.6	13.9	2.7
6	50.8	58.8	8.1	22.4	39.7	13.5	2.6
7	53.7	57.1	6.0	22.9	41.6	10.5	2.7
7	52.9	60.9	8.0	21.2	39.3	12.9	2.5
8	29.8	35.9	6.1	23.0	44.5	10.4	2.7
8	29.8	38.2	8.4	22.5	41.9	14.0	2.6

[1] (29, p. 8).

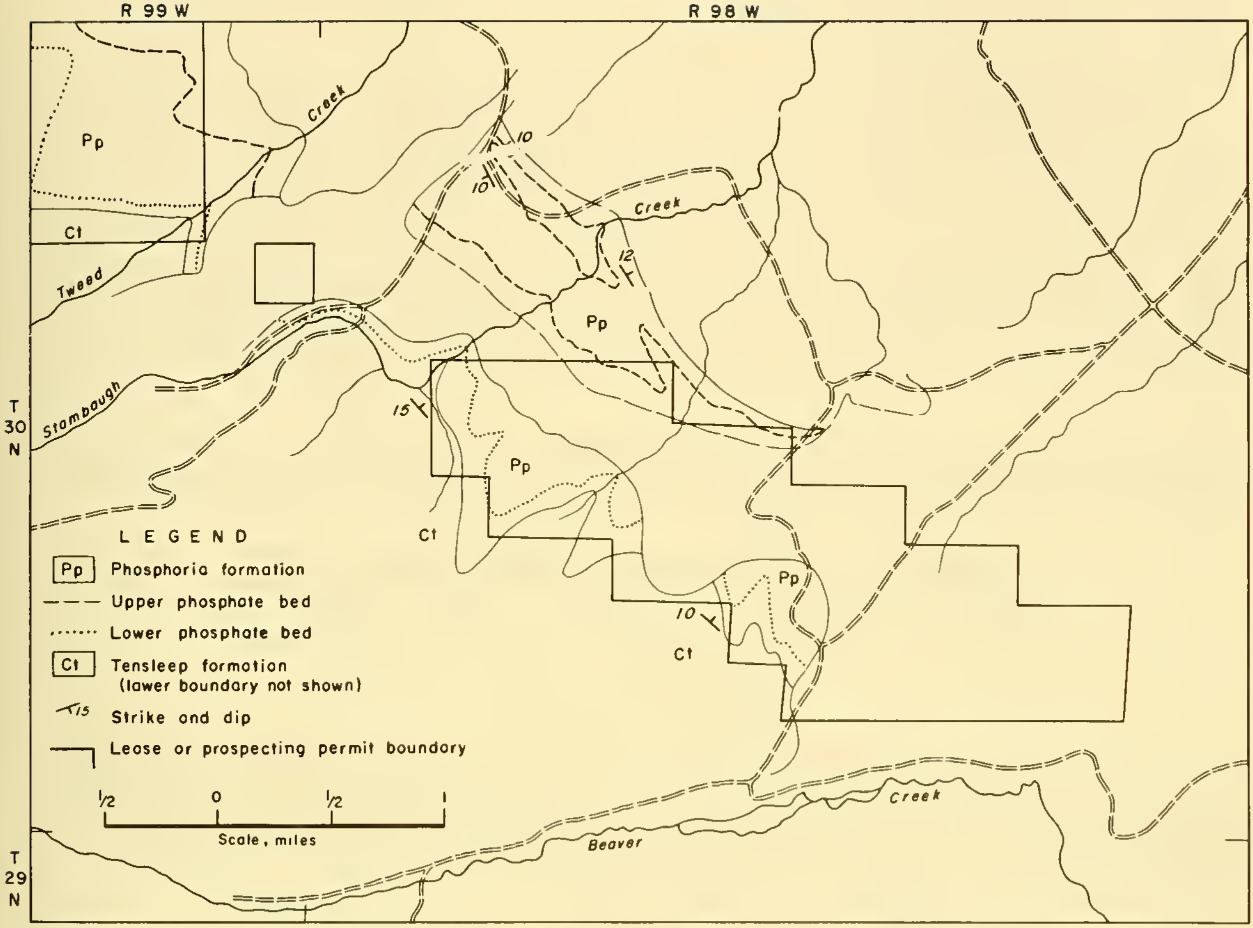

FIGURE 41. - Tweed Creek-Beaver Creek (23). (Modified from Bell, Condit, Gooldy, Mackay.)

The 4-foot sample of 27.6 percent P_2O_5 taken on Tweed Creek is the only other indication of grade of the lower bed in this area. The upper bed was sampled in an earlier survey at Twin Creek and on the anticline south of Tweed Creek. The bed on Twin Creek was lower grade (17 percent P_2O_5) than the one to the south, but it covers a thicker interval (approximately 5-1/2 feet) (13, plate 3).

From Twin Creek to Tweed Creek, the total above drainage entry level resources are approximately 20.3 million tons, with another 7.4 million tons for each 100 feet of depth below entry. All of this rock is considered as beneficiation grade (+18 percent P_2O_5). Most of the phosphate exposures (especially the Meade Peak) in this area are covered by prospecting permits extending north and south from Twin Creek.

Tweed Creek-Beaver Creek

The Meade Peak member has been reported to be less than 1 foot thick at Beaver Creek (fig. 41) and is almost completely missing at Sweetwater River

(13, p. 34); but the Retort member contains a 5-foot bed of +21 percent P_2O_5 rock in a small outcrop south of Beaver Creek (6, p. 71).

Prospecting permits covering about 1,500 acres between Beaver Creek and Stambaugh Creek were granted to Susquehanna Western, Inc., in 1962. The permits cover all of the Meade Peak phosphate exposures and a small part of the Retort member. There is a wide area included in the permit that contains a Tertiary cover of relatively great thickness. It is assumed that the Meade Peak member in this area contains at least a 3-foot bed of +18 percent P_2O_5 rock. The Retort member may contain a 5-foot bed of beneficiation grade rock as it does south of Beaver Creek. Between Twin Creek and Beaver Creek, the Retort member is contained in a small structure south of Tweed Creek (13, plate 3).

Phosphate resources (in millions of short tons of +18 percent rock) in the Retort and Meade Peak members between Tweed Creek and Beaver Creek are described in the following tabulation:

Member	Above drainage entry	100 feet below
Retort........	8.0	0.7
Meade Peak....	7.3	1.0

Sweetwater River

South of Beaver Creek the Phosphoria formation crops out discontinuously for about 17 miles (fig. 42). Total area is about 850 acres, and the formation is covered by the great expanse of Tertiary and Quaternary sediments throughout most of the belt. Most of the occurrences are small, 10 to 20 acres; only a few cover more than 100 acres.

Dips range from about 5° to 20° NE, and many small crossfaults have been projected to cross the Phosphoria formation (6, plate 2). Several large scale faults also offset the formation, the major one is the Beaver Creek Thrust.

Considering total strike length, the Phosphoria formation represents more than 26 million square feet of bed area for every 100 feet of depth. There are only a few of the larger outcrops extending between Beaver Creek and the Sweetwater River that can be considered as potential phosphate areas. The following resources in millions of short tons of +18 percent P_2O_5 rock are estimated for this area as presented in the following tabulation:

Member	Above drainage entry	100 feet below
Retort.........	13.9	2.9
Meade Peak.....	11.1	1.7

These estimates are based on a 5-foot bed in the Retort member to the south and a 3-foot bed in the Meade Peak member.

There is no information on the phosphatic zones south of the Sweetwater River and no estimates have been made. The only outcrop area of appreciable size is south of the Sweetwater River on Sulfur Creek. It is limited in

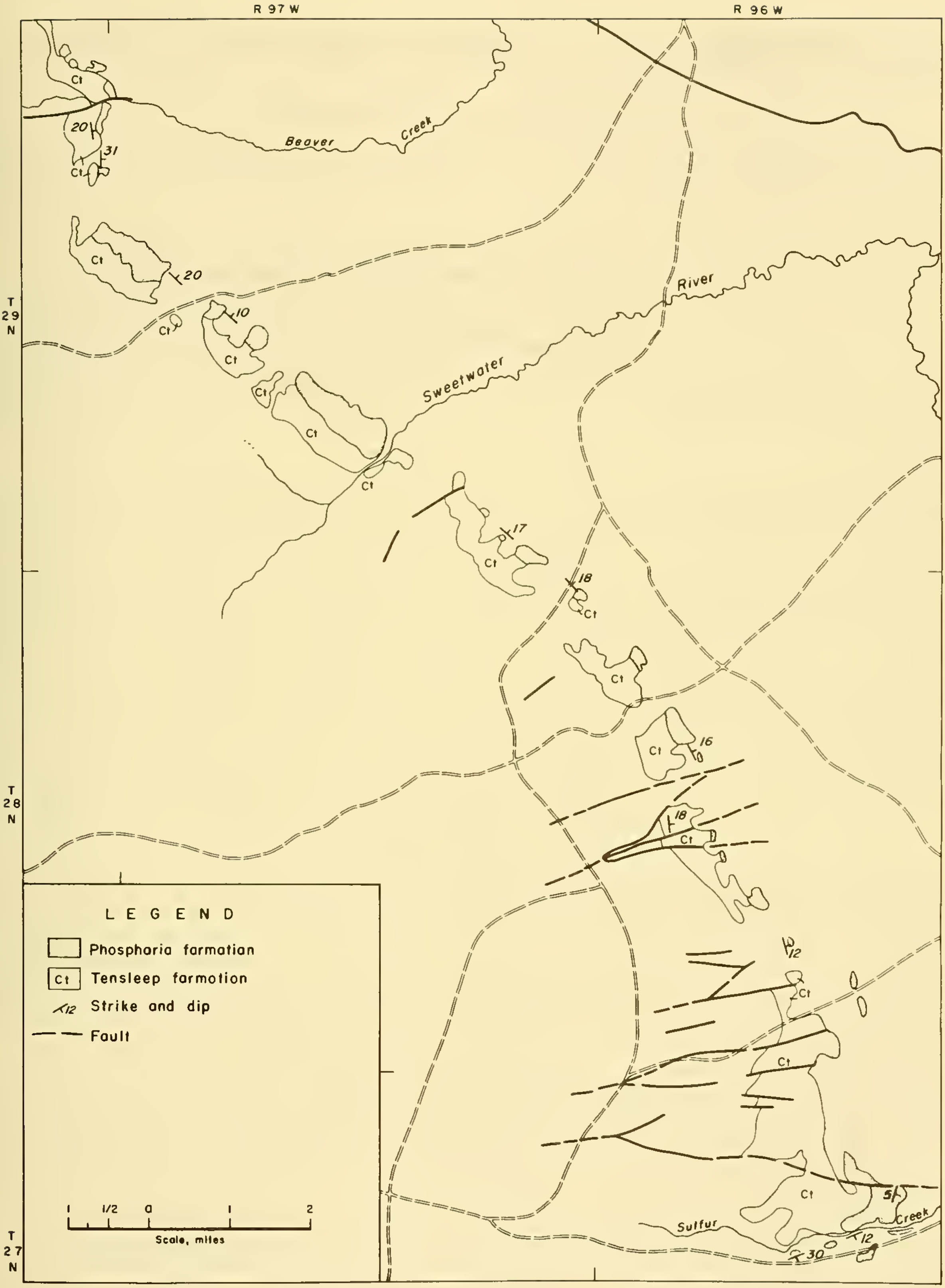

FIGURE 42. - Sweetwater River. (Modified from Bell.)

economic significance by being situated approximately 55 miles, by graveled and paved roads, from the nearest railhead at Lander.

Resource Summary and Potential

The estimated resources in the southeastern Wind River Range district are summarized in table 29.

TABLE 29. - Phosphate rock resources in the southeastern Wind River Range district (million short tons)

Area	Above drainage entry		100 feet below entry	
	+18 percent P_2O_5	+15-18 percent P_2O_5	+18 percent P_2O_5	+15-18 percent P_2O_5
North of Red Creek-Twin Creek divide:				
Retort...............	46.2	44.7	6.7	7.3
Meade Peak...........	52.2	-	7.9	-
Twin Creek to Tweed Creek:				
Retort...............	4.2	-	2.6	-
Meade Peak...........	16.1	-	4.8	-
Tweed Creek to Beaver Creek:				
Retort...............	8.0	-	0.7	-
Meade Peak...........	7.3	-	1.0	-
Beaver Creek to Sweetwater River:				
Retort...............	13.9	-	2.9	-
Meade Peak...........	11.1	-	1.7	-
Total..............	159.4	44.7	28.3	7.3

In view of the wide areas of relatively flat dipping beds throughout most of the district, the resources available by open pit methods are of particular interest.

For the purpose of illustration, a 10:1 waste to ore ratio may be applied to an open pit operation in the Twin Creek area. Here, the above entry resources are about 16 to 17 million tons of +18 percent P_2O_5 rock in the 8-foot Meade Peak member. Field observations and geometric projections of bed profiles against topographic configuration indicate that approximately two-thirds of this rock is available within the limits of a 10:1 waste to ore ratio. Farther north in the area between Cherry Creek and Little Popo Agie River, the Meade Peak bed ranges from 4 to 5 feet in thickness, with about the same relation to the bed and the topography. In this area the amount of rock available by open pit methods would be only 30 to 50 percent of the amount estimated in the above example. If similar restrictions are placed on a possible operation encompassing the entire Meade Peak occurrence in this area, an estimated 18 million tons of +18 percent P_2O_5 rock would be available by open pit methods.

Topography and bed thickness conditions would probably prohibit the use of open pit methods on the Retort bed. Most of the thicknesses are between 3 and 4 feet and a 10:1 waste to ore ratio would, therefore, limit the depth of penetration to between 30 and 40 feet. In addition, the phosphatic zone almost always lies near the base of a 20- to 40-foot bench. The possible mining width on this horizon would, therefore, be limited to a comparatively narrow strip. It is probable that no more than 10 percent of the above drainage resources would be available for strip mining under the above conditions.

The Bureau of Mines conducted extensive studies on the Meade Peak member in the Twin Creek and Popo Agie areas which indicate that the rock occurs under conditions favorable to mining. Later, however, the Natural Resources Research Institute of the University of Wyoming conducted beneficiation tests to determine whether free lime and fluorine could be economically removed from the rock and concluded that commercial exploitation was not feasible at that time (15, p. 56).

In 1963 a uranium beneficiation plant (owned by Susquehanna Western, Inc.) in Riverton became available for possible use in phosphate processing. If these facilities could be economically converted to a wet-process fertilizer plant, the saving in capital investment could possibly bring about exploitation of the phosphate rock in this area. Susquehanna Western, Inc., owns State and Federal leases and Federal prospecting permits on approximately 6,900 acres in the area. This area is conveniently located with respect to the central great plains market region and, in particular, Nebraska, which is a large consumer of phosphate fertilizer products. Transportation of the Twin Creek and Popo Agie rock to the Riverton site would entail roughly 20 miles of road transport to Lander, and then about 25 miles of rail transport to Riverton. Fertilizer produced at Riverton would undoubtedly enjoy a freight rate advantage.

LATENT PHOSPHATE AREAS

In the mountainous region of western Wyoming, there are several other large areas which contain Phosphoria exposures. Some vicinities contain relatively large amounts of ore grade phosphate rock but, for the most part, the resources are very remote and many times are in extremely precipitous country. Access is prohibitive, not to mention the difficulties that would be encountered in transportation of mine products.

There has been little geologic work published recently about these regions, although the northern Hoback Range has been the subject of a number of studies, mainly because of the severe nature of the structures encountered there (see list of references at end of this report). Two earlier surveys covered most of the area--Veatch (61) in the south and Schultz (48) in the north.

Considerable work has been done by oil companies whose main interest is the structure of the folded belt. The Geological Survey did some mapping in the Phosphoria outcrop area, but this work has not yet been published.

There are approximately 260 miles of phosphate outcrop in areas lying in the following topographic divisions:

	Miles
Hoback Range..................	105
Wyoming Range..................	50
South Ridges..................	80
Tump Range....................	25

The phosphate resources have been estimated by the Geological Survey in all but the Tump Range (52, p. 155). These estimated resources above and 1,000 feet below drainage entry level are shown in table 30.

TABLE 30. - Phosphate rock resources in part of Western Wyoming, Sheldon[1] (million short tons)

	+24 percent P_2O_5		+18 percent P_2O_5	
	Above drainage entry	1,000 feet below	Above drainage entry	1,000 feet below
Hoback Range............	319.0	85.1	1,124.0	288.3
Wyoming Range...........	440.4	199.6	662.7	316.7
South Ridges............	175.4	175.4	1,179.2	1,118.0

[1]The figures in the table are adjusted from Sheldon's in order to conform to the areas discussed in this work.

Hoback Range

The Hoback Range encompasses an area of over 800 square miles of extremely rugged topography with difficult access to the phosphate outcrops (fig. 43). The actual limits of this mountain range have not been definitely established, and boundaries have been arbitrarily adjusted to fit the general configuration of the Phosphoria formation. On the north, the range merges into the Gros Ventre Range where the boundary is a trend of igneous and metamorphic rocks; to the south, the same topography continues as the Wyoming Range. Local relief of 2,000 feet is not uncommon, and the exposures of the phosphate member have a range of elevation from 6,000 feet to more than 9,500 feet.

The Snake River Canyon Highway (U.S. 89) cuts a faulted outcrop of the phosphate member near Astoria Hot Springs (fig. 44) and is near a faulted section at Leeks Canyon about 2 miles south of Jackson, Wyo. Other gravel roads approach the member from comparatively long distances; the only access to the main areas of phosphate outcrops is by steep forest trails.

All of the Phosphoria formation outcrops are within the boundaries of Teton and Bridger National Forests. The area is covered by topographic maps and aerial photographs.

The main ridges and high points of topography in the Hoback Range lie on large-scale thrustfaults, similar to the rest of the western Wyoming folded belt. The most complex structure that affects the Phosphoria formation is in

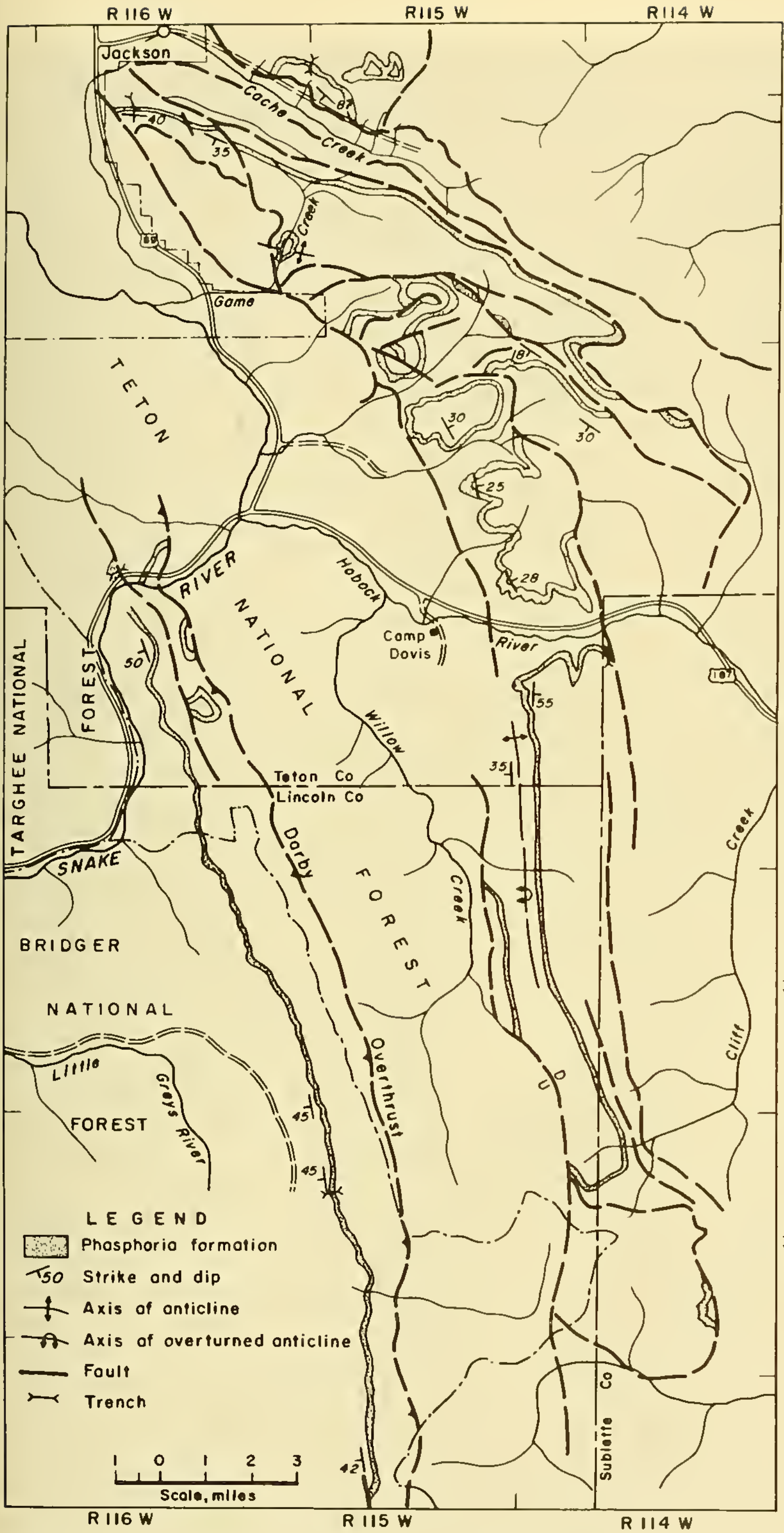

FIGURE 43. - Hoback Range. (Modified from Eardley, Love, 1955 and 1956, Nelson, Ross, Schultz, 1914, Van Dyke.)

the northern part of the area where the phosphate member outcrops in an arcuate pattern interrupted in many places by thrust and normal faults. To the south, across the Hoback River, the structures are relatively long and straight and follow the trend of the main ridges.

In the north, what appears to be the longest unfaulted trend, the Phosphoria strikes northwest and follows Snow King Ridge for about 2 miles. This trend was trenched and sampled by the Geological Survey in 1963 (fig. 45). A ±9-foot phosphatic zone split by about a 4- to 6-foot carbonate bed 3 feet above the base was exposed (fig. 46). The carbonate rock may represent a surface slump block, and so the actual thickness of the phosphatic zone could be 6 to 7 feet. The latter figure corresponds with thickness found in a trench in flat-lying beds on Game Creek (fig. 47).

Another trench was excavated and sampled in a fault block on the north side of Cache Creek. A comparatively lean phosphate section is reported to be present in this trench.

FIGURE 44. - Meade Peak Member (Dark) at Astoria Hot Springs, Teton County.

FIGURE 45. - Trench in the Phosphoria Formation Near the Head of Leeks Canyon, Teton County.

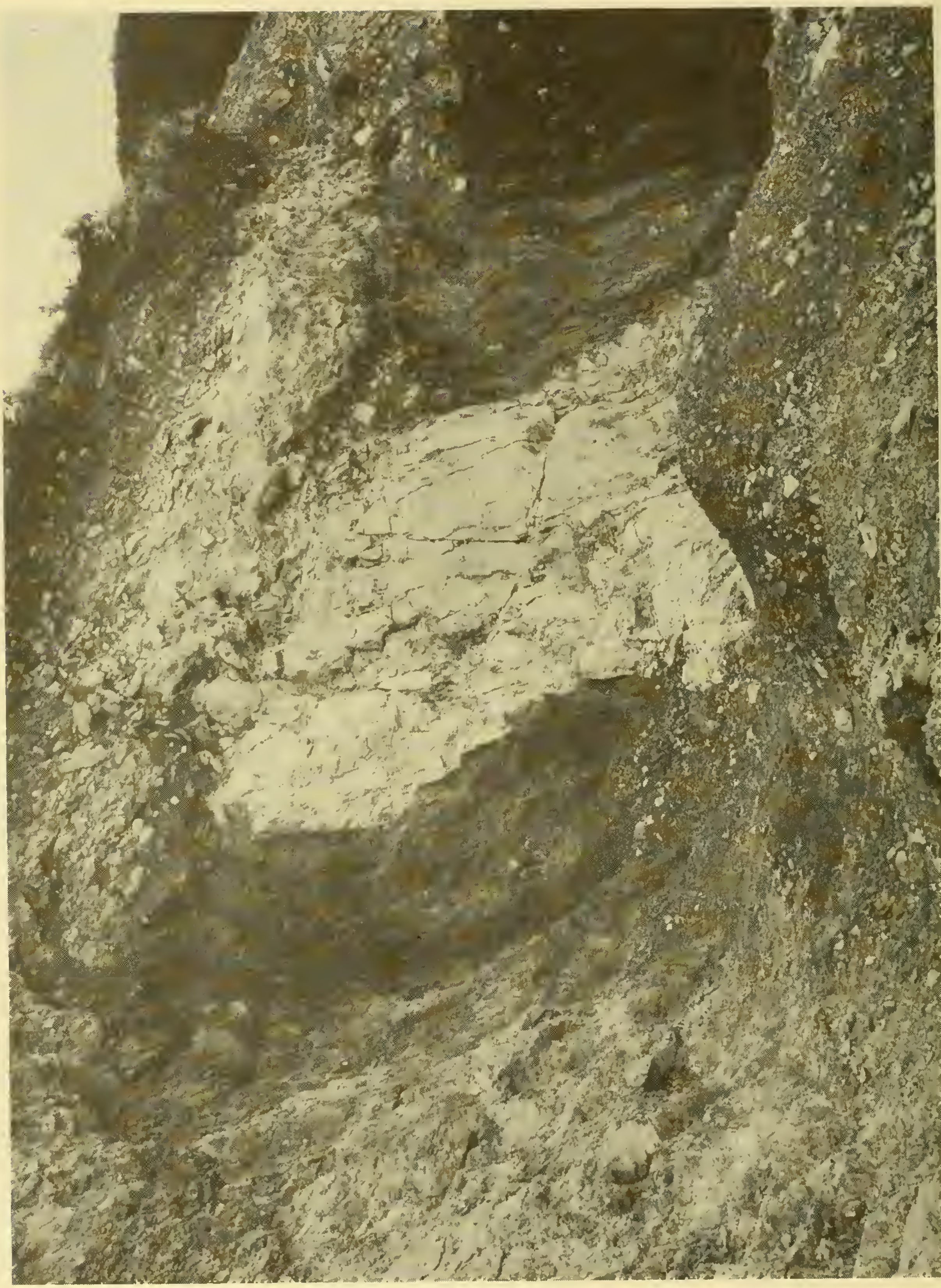

FIGURE 46. - Basal Phosphatic Zone, Head of Leeks Canyon.

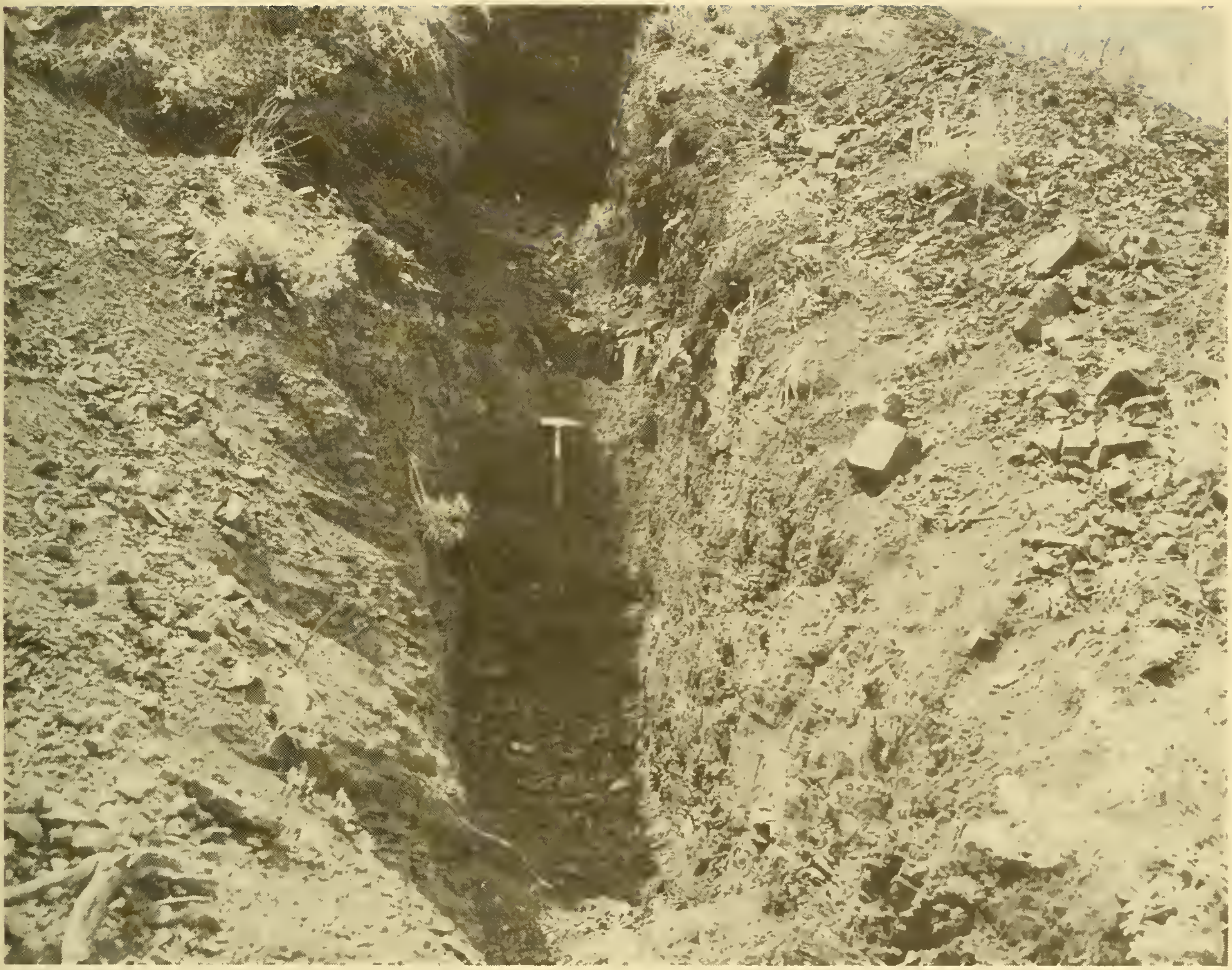

FIGURE 47. - Trench in the Lower Part of the Meade Peak Member on Game Creek, Teton County.

South of the Hoback River the Phosphoria formation continues on the east limb of an anticline for a strike distance of about 13 miles. This outcrop dips steeply to the east, and near the middle of the trend it is overturned. The formation traces a south-plunging anticlinal nose on the south wall of Cliff Creek canyon. It is faulted out over most of the west limb of this anticline, with the exception of a west-dipping outcrop about 3.5 miles long near the middle. The exposure was trenched and sampled by the Geological Survey near the Hoback River (54, pp. 24-25). Sample analyses indicate a zone of phosphate enrichment both at the top and bottom (table 31). This trench is the only representative section for the outcrop; however, the lower zone and possibly a thinner upper zone can be recognized where the formation crosses a divide west of Clause Peak.

Paralleling the above outcrop about 6 miles to the west is another continuous trend that extends in a north-south direction approximately 24 miles. This is mainly a single, steep, west-dipping exposure that is faulted off at both ends. Toward the north end an anticlinal structure is developed in a in a fault structure. The Phosphoria formation is exposed again in a paralleling syncline to the east.

TABLE 31. - Meade Peak section in Buck Creek Canyon, Teton County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Carbonate rock	2.0	1.4
Phosphate rock	0.8	29.2
Carbonate rock	0.8	2.6
Phosphate rock	2.0	20.8
Mudstone	9.0	1.8
Phosphate rock	0.8	23.0
Carbonate rock	2.3	2.5
Phosphate rock	1.5	15.0
Mudstone	2.9	3.2
Phosphate rock and mudstone	3.7	17.7
Mudstone and carbonate rock	9.4	4.4
Phosphatic mudstone	1.0	12.6
Carbonate rock	0.6	1.3
Phosphate rock	3.1	27.6
Carbonate rock	0.8	3.1
Phosphate rock	0.6	30.4
Mudstone	1.2	3.9
Phosphate rock	2.5	29.0

[1] (54, pp. 24-25).

In this exposure the Meade Peak member was sampled at two places by the Geological Survey; one in a road cut at the north end (table 32) and the other near the south end (table 33; 54, pp. 21-24). In both sections the phosphate enrichment is near the base with little indication of any appreciable enrichment in the upper part of the section.

TABLE 32. - Meade Peak section at Astoria Hot Springs, Teton County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Phosphatic chert	2.1	13.6
Mudstone and thin beds of phosphate rock	11.1	2.5
Phosphate rock	1.0	17.4
Carbonate rock and mudstone	3.3	1.5
Phosphate rock	1.3	15.3
Phosphatic carbonate rock and mudstone	8.0	7.6
Phosphatic carbonate rock	6.3	10.4
Carbonate rock and mudstone	5.4	4.1
Mudstone and phosphate rock	3.3	10.2
Phosphate rock	3.6	22.8
Carbonate rock	4.8	2.4
Phosphate rock	0.6	28.9
Mudstone	1.1	4.4
Phosphate rock	0.8	34.8
Phosphatic chert	0.9	13.4

[1] (54, pp. 22-23).

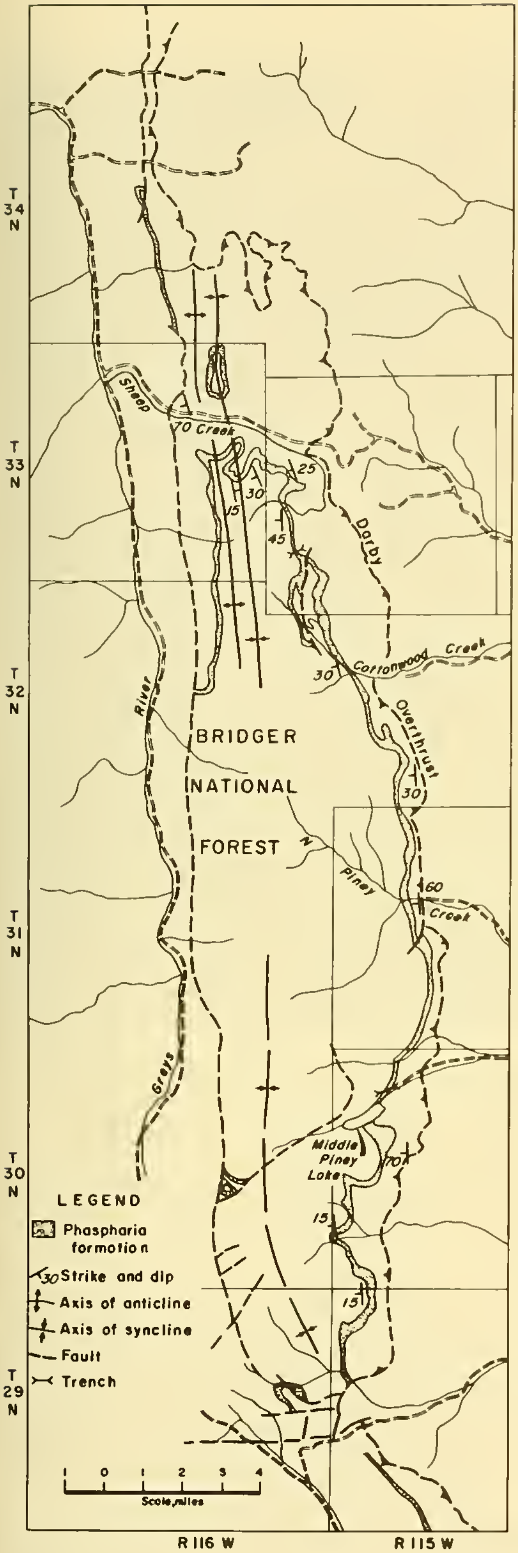

FIGURE 48. - Wyoming Range. (Modified from Sheldon, 1963, Shultz, 1914.)

TABLE 33. - Meade Peak section, North Fork Steer Creek, Lincoln County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Phosphate rock............	0.8	24.6
Mudstone..................	12.8	1.4
Phosphatic mudstone.......	0.5	14.4
Mudstone..................	6.0	0.9
Phosphate rock and mudstone	1.9	14.7
Carbonate rock and mudstone	4.3	1.7
Phosphatic mudstone.......	1.3	14.2
Carbonate rock............	1.9	1.3
Phosphatic mudstone.......	2.7	13.3
Mudstone and carbonate rock	6.6	2.5
Phosphatic mudstone.......	1.0	11.8
Carbonate rock............	1.9	2.0
Mudstone and phosphate rock	3.6	18.8
Carbonate rock............	3.5	5.1
Phosphate rock............	3.3	24.2
Phosphatic mudstone.......	1.4	8.4

[1] (11, pp. 18-19).

Wyoming Range

The Wyoming Range (fig. 48) includes several different mountainous masses and, for the purpose of this work, it has been classified as a continuation of the topography of the Hoback Range. The topography of the range is extremely rugged, and access to outcrops of the Phosphoria formation is difficult. Middle Piney and South Cottonwood Creeks provide access from the east, and the area is crossed by roads on the south and near the middle. The Greys River Forest Service road forms the west boundary to the area. A considerable amount of foot travel is necessary to reach exposures of the Phosphoria formation from any of these access routes. All phosphate occurrences in the area are within the boundaries of the Bridger National Forest and topographic map and aerial photo coverage is available.

Typical thrust structures of the western Wyoming folded belt predominate this area. Several folds occur in the area as well, mainly in the central phosphate belt. Major structure features of the range are controlled by several comparatively large scale thrust and normal faults.

The Phosphoria formation was trenched and sampled at the Sheep Creek-Cottonwood Creek divide (table 34) and near Middle Piney Lake (table 35) by the Geological Survey. From the trench at Middle Piney Lake to the trench at the Sheep Creek-Cottonwood Creek divide the Meade Peak member thickens from a depth of 64 feet to about 125 feet. There is also much difference in the richness of the phosphatic section since the northern trench exhibits thicker phosphate beds at the base. There are no +3-foot phosphate beds containing +18 percent P_2O_5 at the Middle Piney Lake locality.

TABLE 34. - Meade Peak section, South Cottonwood Creek-Sheep Creek Divide, Lincoln County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Oolite.......................................	1.0	([2])
Oolite.......................................	1.3	32.6
Siltstone....................................	1.0	([2])
Oolite.......................................	1.0	19.3
Siltstone....................................	1.0	([2])
Oolite.......................................	1.0	19.3
Siltstone and shale..........................	5.0	([3])
Shale (?)....................................	0.5	35.8
Siltstone, limestone, and chert..............	70.1	([3])
Oolite (?)...................................	3.3	8.6
Shale..	4.5	13.4
Siltstone and shale..........................	18.8	([3])
Oolite.......................................	2.5	([2])
Oolite.......................................	2.5	25.9
Siltstone (?)................................	2.4	25.8
Siltstone....................................	5.8	([3])
Oolite.......................................	1.8	29.0
Phosphate rock...............................	1.3	32.5

[1] (37, pp. 93-95).
[2]Not determined.
[3]Mostly not determined.

In both locations the Meade Peak member is underlain by a carbonate rock unit. At the time the work was done this unit was identified as the Wells formation. Since the recent classification of this basal carbonate-mudstone sequence at other localities as the Grandeur tongue of the Park City formation, the same terminology may also be applied here. The thickness of the unit was not determined at the South Cottonwood trench, but it was 9 feet thick at Middle Piney Lakes. The Sheep Creek-Cottonwood Creek trench is caved, although the basal bed is traceable for several miles to the north, particularly along the breaks on the south wall of Sheep Creek Canyon (fig. 49).

FIGURE 49. - Meade Peak Member Along the South Wall of Sheep Creek Canyon, Lincoln County.

TABLE 35. - Meade Peak section, Middle Piney Lake, Sublette County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Mudstone, carbonate rock, chert and thin beds of phosphate rock............................	40.0	1.1
Phosphate rock and carbonate rock............	3.0	15.3
Carbonate rock, argillaceous.................	1.2	1.5
Phosphate rock, carbonate rock and mudstone...	4.4	15.9
Carbonate rock and mudstone..................	7.3	2.9
Phosphate rock...............................	5.0	15.1
Carbonate rock...............................	0.8	1.6
Phosphate rock and phosphatic chert..........	2.3	27.6

[1] (53, p. 7).

Resources and Potential of the Hoback and Wyoming Ranges

The total latent resources in the Hoback and Wyoming Ranges, as calculated in the course of this investigation, are shown in table 36.

TABLE 36. - Latent phosphate rock resources in the Hoback and Wyoming Ranges (million short tons)

Range	Grade, percent P_2O_5	Above drainage entry	100 feet below
	+24	307	8
Hoback	+18	934	26
	+10	1,689	47
	+24	159	7
Wyoming	+18	499	23
	+10	691	43

The Southern Hoback and the Wyoming Ranges are similar with respect to topography and access. The entire area is both extremely rugged and very remote. Transport of any product to processing facilities is not economically feasible at the present time, and severe winters in the elevations of the phosphate belt would shorten a mining season considerably. The northern part of the Hoback Range is more accessible from highways, but it is still remote from rail facilities.

South Ridges

General

The South Ridges include three separate, north-south trending ridges with single, west-dipping Phosphoria outcrops that extend for a total distance of over 80 miles (fig. 50). On the east the Phosphoria follows the Packsaddle-Deadline Ridge crest, and in the middle and western trends it follows Absaroka and Commissary Ridges. The outcrops are faulted out and repeated in several localities and, in the northern end and the westernmost trend, there is some folding.

The general topography is extremely rugged and precipitous on the west with subdued areas in the east. Access to all of the outcrops requires considerable travel by trail. In the extreme south end, a previous phosphate mining operation can be reached by a gravel surfaced road from LaBarge, Wyo. The road follows LaBarge Creek to its headwaters at the northern end of the area. The road continues on to U.S. Highway 95 about 15 miles south of Afton, Wyo. The Phosphoria exposures lie mainly on Federal land, and map and aerial photc coverages are available.

Western Wyoming thrust structure is the dominant feature of the geology in this district. All of the ridges on which the Phosphoria formation occurs are underlain by thrusts; the Phosphoria itself is affected by a considerable

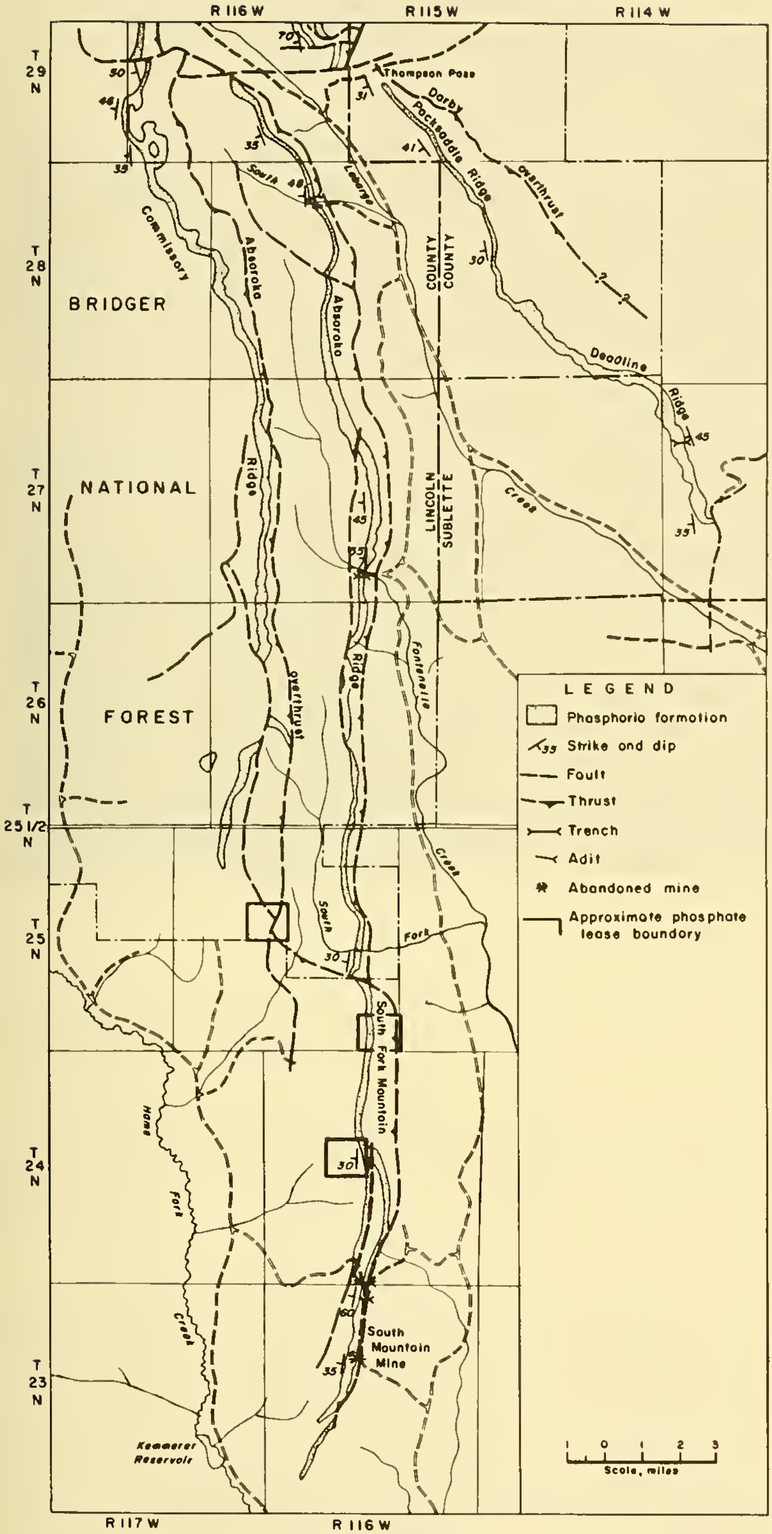

FIGURE 50. - South Ridges. (Modified from Fruchey, Furer, Sheldon, 1963, Schultz, 1914.)

amount of faulting. On the boundary of the area there is a particularly high concentration of faults, most of which are of the cross-fault type. There are also some folds between Deadline Ridge and LaBarge Ridge in the south, but the trends of Phosphoria that surround these structures are all west dipping. To the north, the structure of the two western trends is essentially a west-dipping homocline with no intervening folds. The western trend, on the other hand, extends through several areas of folding and is similarly affected.

There have been three complete sections and one partial section of the Phosphoria formation measured in this area. The thickness ranges from about 310 to 395 feet, with the thickest section on the eastern trend. The Meade Peak member ranged from 60 to 73 feet; the thickest section is at Fontenelle Creek (table 37).

The eastern trend extends for about 18 miles along Packsaddle and Deadline Ridges. The Phosphoria formation dips off the west slope of the ridges throughout the entire outcrop. Near the south end, the formation was trenched and sampled by the Geological Survey, and the phosphatic section in this trench was found to be of low grade (table 38). There are no +3-foot beds containing +18 percent P_2O_5 phosphate beds in the Meade Peak member. The Retort member contains one +18 percent bed, but it is not considered sufficient to warrant estimating resources.

TABLE 37. - Meade Peak section on Fontenelle Creek, Lincoln County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Carbonate rock and mudstone..................	16.9	1.3
Phosphate rock..............................	2.6	34.3
Mudstone....................................	2.7	0.5
Phosphate rock..............................	1.0	31.8
Mudstone....................................	1.1	5.3
Phosphate rock..............................	3.6	26.8
Phosphate rock and mudstone..................	4.3	19.3
Mudstone and carbonate rock..................	19.7	2.2
Phosphatic mudstone.........................	3.9	14.4
Carbonate rock and mudstone..................	12.1	3.6
Phosphate rock and carbonate rock............	5.8	16.9

[1] (53, pp. 12-13).

TABLE 38. - Part of the Phosphoria formation on Dealine Ridge, Sublette County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Retort, lower part: Phosphate rock and mudstone....................................	3.8	23.4
Rex-Franson: Carbonate rock, mudstone, and chert.......................................	270.5	-
Meade Peak:		
Mudstone and chert.........................	1.3	3.5
Phosphate rock.............................	1.3	26.7
Covered interval...........................	5.0	-
Mudstone and carbonate rock................	33.3	2.2
Phosphatic mudstone........................	0.8	12.6
Phosphate rock.............................	1.4	24.2
Carbonate rock and mudstone................	8.5	3.9
Phosphate rock.............................	3.5	17.9
Carbonate rock.............................	3.4	2.1
Phosphate rock.............................	1.0	18.8
Phosphate carbonate rock...................	1.2	14.4
Wells formation............................	-	-

[1] (53, pp. 9-10).

The middle trend includes about 44 miles of phosphate exposures that contain several long outcrops in relatively unfaulted areas. There are also areas that are quite severely faulted. All of the phosphate outcrops examined in the present survey are west dipping.

FIGURE 51. - South Mountain Open Pit.

On the south end of this trend, about 10 miles north of Kemmerer, an attempt was made in 1947 by Phosphate Mines Inc. to develop an open pit and underground mine (fig. 51).

The mine operated intermittently for a few years; however, production was small. The mine property and State lease (640 acres) are now held by the Kemmerer Coal Co. As yet, the company has made no attempt to explore the old workings.

In this locality the Meade Peak crops out just under the crest of the ridge and dips 35° to 45° W. The phosphatic section is lean (table 39), but near the head of Wheat Creek the phosphate grade increases (table 40). The richest beds are near the base of the phosphate member. In an underground crosscut at the Wheat Creek locality it was reported that a 6-foot bed of +30 percent P_2O_5 rock was intersected. North of Wheat Creek, the nearest sampled section is at Fontenelle Creek, a distance of about 20 miles. At this locality (see table 37), the Meade Peak member has a richer section than at Wheat Creek.

TABLE 39. - Meade Peak section at South Mountain pit and underground crosscut, Lincoln County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Phosphate rock................................	1.8	22.6
Mudstone......................................	4.1	1.4
Phosphate rock................................	0.5	27.3
Mudstone......................................	0.8	3.2
Phosphatic mudstone...........................	2.0	13.6
Mudstone and carbonate rock...................	26.0	3.7
Phosphate rock................................	2.9	18.9
Carbonate rock................................	3.0	1.5
Phosphatic mudstone...........................	2.2	10.2
Phosphatic carbonate rock.....................	8.1	10.1
Covered interval..............................	5.0-10.0	-
Phosphate rock (underground)..................	2.7	20.7

[1] (53, pp. 23-24).

TABLE 40. - Meade Peak section near the head of Wheat Creek, Lincoln County[1]

Litholoty	Thickness, feet	Grade, percent P_2O_5
Phosphate rock................................	0.7	17.4
Mudstone and carbonate rock...................	2.5	1.0
Phosphatic mudstone...........................	4.0	11.0
Mudstone and carbonate rock...................	20.9	2.4
Phosphatic mudstone...........................	1.0	12.2
Carbonate rock................................	0.5	1.4
Phosphatic carbonate rock.....................	3.4	9.1
Phosphate rock................................	2.2	16.9
Carbonate rock and mudstone...................	5.0	4.3
Mudstone and phosphate rock...................	5.4	12.4
Phosphate rock................................	4.1	21.3
Carbonate rock................................	3.2	4.5
Phosphate rock................................	3.8	24.2
Mudstone......................................	1.8	2.0
Phosphate rock and mudstone...................	1.9	22.2

[1] (53, pp. 21-22).

Another trench was excavated by the Geological Survey about 11 miles north of Fontenelle Creek on the South Fork of LaBarge Creek. About 6 feet of +23 percent P_2O_5 rock was exposed near the top of the Meade Peak member (37, plate 1). At the time of the Bureau of Mines investigation in 1964, the trench was caved and no representative thickness or grade could be determined, but high-grade float was present on the surface (fig. 52).

Most of the phosphate exposures on Absaroka Ridge are dipping off the hill and are adaptable to open pit methods (fig. 53). Dips range from 30° to

FIGURE 52. - Meade Peak Trench, South Fork LaBarge Creek, Lincoln County.

60° W throughout most of the trend, and several areas are affected by faulting. Access to most of the outcrop is comparatively easy, although it is a considerable distance to the railhead north of Kemmerer.

The Phosphoria formation crops out in a highly precipitous area west of Absaroka Ridge and follows the trend of Commissary Ridge. Practically all of the exposures occur at an elevation of 9,000 to 10,000 feet, and much of the trend lies well above 9,500 feet. Access to this area is extremely difficult, usually requiring several miles of trail travel and considerable climbing.

Resources and Potential

On the eastern trend on Packsaddle and Deadline Ridges, Sheldon estimates 107.7 million tons of +18 percent P_2O_5 phosphate resources above drainage level (52, p. 155). This is based on the 3.8-foot bed of phosphate rock found in the Retort member.

FIGURE 53. - West Dipping Meade Peak Member North of Fontenelle Creek, Lincoln County.

The Absaroka Ridge occurrences contain comparatively rich sections, and considerable resources both the the latent and low potential class can be estimated. The south end does not contain any beds applicable to this study, although in Wheat Creek the phosphatic section develops into thicker and higher grade beds. The Fontenelle section contains the richest beds. At least one bed in the South LaBarge Creek trench appeared to be of relatively high grade. Based on all available data the total resources are shown in table 41.

TABLE 41. - Latent and potential phosphate rock resources on Absaroka Ridge

Grade, percent P_2O_5	Above drainage level	100 feet below
+24........................	104.3	12.1
+18........................	230.5	26.6
+10........................	290.1	33.3

In the Fontenelle Creek area the upper +34 percent P_2O_5 bed could possibly be classed separately as available +31 percent rock, even though it is not quite 3 feet thick. In this event, there would be about 30 million tons of high-grade rock in the area.

All of the resources lying south of the South Fork of Fontenelle Creek are (about 35 percent of the total resources listed for Absaroka Ridge) in the low potential class.

There is ample electrical power available at Kemmerer for any phosphate industrial facility. A recently constructed 235-kilowatt line extends from the Flaming Gorge Dam in northeastern Utah to Kemmerer (see fig. 5).

For the exposure on Commissary Ridge there is very little information on which to base a resource estimate. The Geological Survey sampled a partial section northwest of Lake Alice and exposed an upper bed of about 3 feet of at least +18 percent P_2O_5 rock (37, plate 1). Using this data and the information from sampled sections on Absaroka Ridge the latent resources of this trend are shown in table 42.

TABLE 42. - Latent phosphate rock resources on Commissary Ridge (million short tons)

Grade, percent P_2O_5	Above drainage entry	100 feet below
+24	40.6	6.2
+18	68.3	10.2
+10	102.4	15.3

Tump Range

The Tump Range is a comparatively narrow series of ridges that extends for about 45 miles in a northsouth direction (fig. 54). It merges with the Salt River Range on the north and grades into more plateaulike topography south of Twin Creek. The range forms the divide between the Great Basin and the Colorado River drainages throughout most of the length.

The outcrops of phosphate in the southern end of the range are about 3 miles from U.S. Highway 30N. A gravel road up Rock Creek parallels the outcrop, and several access roads approach the exposures from other directions. Additional access to the range and phosphate deposits is from Cokeville, which is about 8 miles from the nearest phosphate outcrop. Several gravel roads parallel and approach the Phosphoria outcrops in this part of the range. The Union Pacific Railroad follows Highway 30N along the southern part of the range.

The topography in the Tump Range is not as rugged as that in the Salt River Range, but there is abrupt local relief of 200 to 1,000 feet. Most of the higher elevations in the area are the result of gravel terraces that cover the phosphate in a number of places and at different levels.

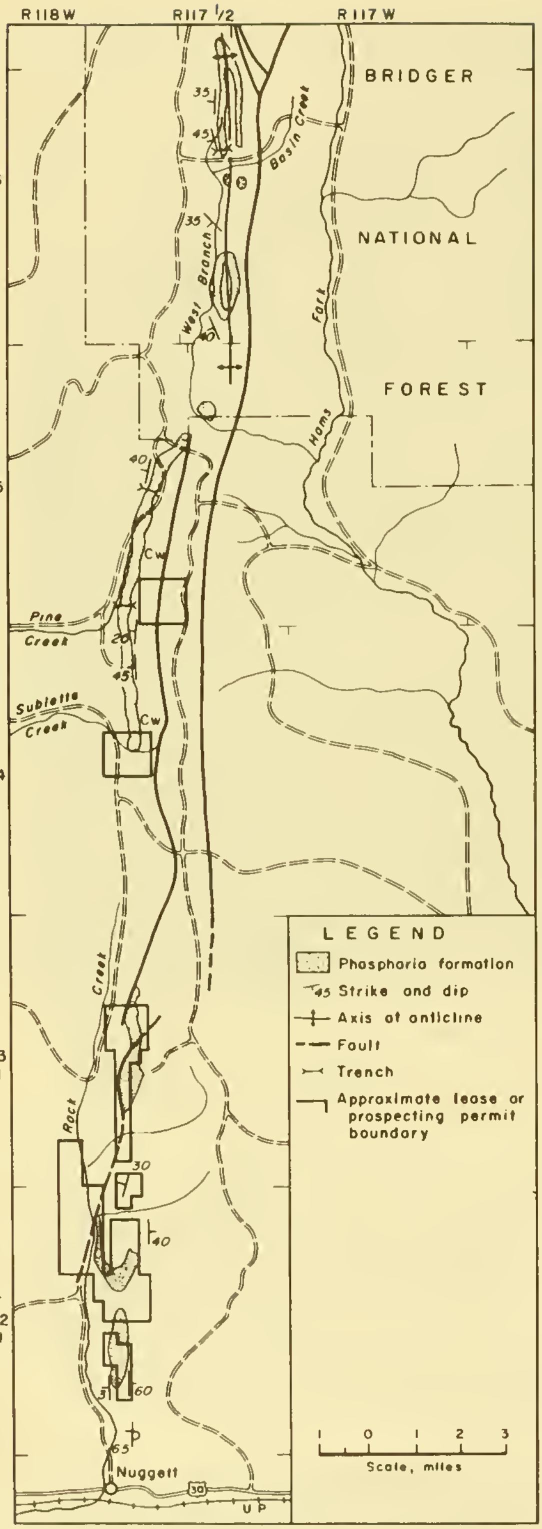

FIGURE 54. - Tump Range. (Modified from Love, 1955, Veatch.)

The rocks exposed range from the Devonian Darby formation to the Tertiary Wasatch formation. The main basal unit of the section is the Wells formation, which is overlain by the Phosphoria formation and a thick section of Mesozoic strata. The Wasatch formation covers a large area on the flanks of the main ridges.

The Phosphoria crops out in an anticlinal structure near the edge of a thrust zone that lies mainly in the Wells formation. This anticline is broken in places by a relatively large normal fault with the upthrown block on the east. The structure appears to become more complex to the south and the Phosphoria is displaced in several places by faults. A short distance north of Nugget, the anticlinal structure is overturned.

The Phosphoria formation has been trenched and sampled at several locations. On the North Fork of Pine Creek, the complete Phosphoria interval was found to be just under 300 feet thick (39, pp. 28-32). On Dempsey Ridge the formation is just under 600 feet thick (37, pp. 123-127). The Meade Peak member varies between about 58 and 66 feet in the northern part of the range, but increases to approximately 87 feet on Dempsey Ridge.

The Tump Range contains about 22 miles of Phosphoria formation outcrops lying in a faulted anticlinal structure. At the north end the formation is covered by younger sediments. This is also true of the southern end, but the structure is somewhat more complicated.

The Phosphoria traces two closed structures of an anticlinal trend in the north end of the area. These exposures are covered, in some places, by terraced Tertiary Wasatch gravel deposits, and in some places they are interrupted by faulting. There are several levels of terracing in this area where the Phosphoria is covered. The axis of the anticline either follows or closely parallels the West

Branch of Hams Fork Creek. Immediately to the east, the anticline rides on a thrustfault.

Trenching and sampling by the Geological Survey indicates that grade diminishes from north to south. The Basin Creek trench (table 43) exposed nearly 15 feet of +18 percent P_2O_5 rock in the Retort member (53, pp. 15-17); however, about a mile to the south this interval was very lean (53, p. 19). Although there is a comparatively thick phosphatic section here, the above-drainage bed areas are small because of the low relief. In addition, the area of outcrop represented by the Basin Creek trench lies in a closed basin and access is difficult. The closest route to Cokeville is about 25 miles involving a 400-foot climb over the ridge on the west side. Above and 100 feet below drainage entry level, resources for this area in million short tons are:

Grade, percent P_2O_5	+31	+24	+18	+10
Above drainage entry.......	2.7	9.1	12.0	36.0
100 feet below.............	1.4	4.7	6.2	18.6

TABLE 43. - Partial section of the Phosphoria formation, Basin Creek, Lincoln County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Retort (?) member:		
Phosphate rock and phosphatic mudstone.......	12.7	21.2
Chert, carbonate rock and mudstone...........	21.0	-
Phosphate rock...............................	2.1	21.6
Rex (?)-Franson (?) members: Carbonate rock, chert, and mudstone..........................	141.8	-
Meade Peak member:		
Mudstone.....................................	1.0	-
Phosphate rock...............................	3.1	35.1
Phosphatic mudstone..........................	2.7	10.7
Phosphate rock...............................	5.1	28.6
Mudstone and phosphate rock..................	4.5	7.9
Mudstone.....................................	15.4	-
Phosphate rock...............................	4.9	18.6
Carbonate rock and mudstone..................	2.8	2.1
Phosphate rock...............................	6.0	19.3
Carbonate rock...............................	2.5	3.6
Phosphate rock...............................	5.1	23.9
Carbonate rock and mudstone..................	3.5	3.4
Phosphate rock...............................	1.7	29.9
Mudstone.....................................	4.9	3.1
Phosphate rock...............................	2.6	24.8

[1] (53, pp. 15-17).

In the Pine Creek and Sublette Creek drainage the Phosphoria formation crops out in a continuous, west-dipping trend for about 7 miles. Traces of the formation have been mapped to the east of the main trend, on the east flank of the anticline. These occurrences are short since the anticline is broken by a relatively large thrustfault, and the Phosphoria formation is apparently overridden by the upper plate. The anticline appears to be best developed where the structures are crossed by the headwaters of Sublette Creek. These small, east flank exposures are not considered in the estimate of resources for the Tump Range.

This trend was trenched and sampled by the Geological Survey at the North and Middle Forks of Pin Creek (table 44). The total section of the Meade Peak member is comparatively low grade; however, there is 7.5 to 9 feet of 30 percent P_2O_5 rock at the top of the member. This zone is split by a 1.5-foot bed of barren mudstone or limestone in both trenches. Resources in this area are estimated as follows (millions of short tons):

Grade, percent P_2O_5	+31	+24	+18	+10
Above drainage entry...	10.3	24.0	36.2	161.0
100 feet below........	1.7	3.9	5.8	25.9

The ±2.5 miles of outcrop from Pine Creek north to the West Branch of Hams Fork dip into the hill, while the ±5 miles of outcrop from Pine Creek south to Sublette Creek dip off the hill. Most of the dips range from 35° to 45° W, but there is a small area near the Middle Fork trench that dips about 10° W.

The section contains a relatively good phosphate bed at the top of the Meade Peak member, and it is the most important feature of the area. There is a substantial outcrop that dips off the hill and is available for open pit mining. It is estimated that there is 1 million tons of +24 percent P_2O_5 available on this trend. The average grade would be less than that found in the trenches (+31 percent P_2O_5), but allowing for the normal decrease in grade below the weathered zone, it would still be about 27 to 28 percent P_2O_5.

This area has an immediate potential for a relatively small tonnage of open pit rock, and a more distant potential for a larger amount of phosphate rock above drainage level. The main advantage is that the trend lies 10 to 12 miles from the railroad at Cokeville and within reasonable rail distance from the processing facilities at Leefe to the south and the Sublette Range phosphate area to the north.

Farther south the Phosphoria formation crops out in a discontinuous trend in a highly folded and faulted area on Dempsey Ridge north of Nugget Station. This part of the Tump Range was mapped geologically in 1905 (61, plate 3). No subsequent mapping has been published, but McKelvey reports that a section of the Meade Peak outcrops on Dempsey Ridge about one-half mile east of Rock Creek (37, pp. 123-127). This section was trenched and sampled, but no analyses were made. Upper and lower phosphate beds, each about 3 feet thick, were delineated, but the phosphate contents were only estimated. The lack of a rich phosphatic section is indicated by the scarcity of float on the surface.

There has been a certain amount of interest in this area and some of the outcrops are covered by State leases and Federal prospecting permits. The deposit is well situated with respect to transportation and is close to processing facilities at Leefe.

TABLE 44. - Meade Peak sections, North and Middle Forks Pine Creek, Lincoln County

Lithology	Thickness, feet	Grade, percent P_2O_5
North Fork:[1]		
Mudstone and limestone	33.4	2.9
Phosphate rock	3.5	34.7
Mudstone	1.4	2.8
Phosphate rock	5.4	26.7
Mudstone	4.0	2.2
Phosphatic mudstone and phosphate rock	3.5	11.4
Mudstone	11.5	2.3
Phosphatic mudstone	2.0	10.0
Mudstone	3.6	6.7
Phosphate rock	3.9	15.2
Limestone	2.8	1.0
Phosphate rock and limestone	6.3	15.7
Limestone and chert	3.7	4.8
Phosphate rock and phosphatic mudstone	6.3	21.6
Middle Fork:[2]		
Mudstone and limestone	16.9	3.6
Phosphate rock	3.0	33.5
Limestone and mudstone	1.6	2.5
Phosphate rock	4.4	27.3
Mudstone, limestone, and phosphate rock	8.2	4.4
Phosphate rock	1.8	18.3
Mudstone, limestone, and phosphate rock	18.5	3.0
Phosphatic mudstone	6.3	12.1
Limestone	3.0	0.7
Phosphate rock	4.7	15.0
Limestone	2.4	5.0
Phosphate rock	3.1	16.1
Limestone and phosphatic mudstone	4.4	4.5
Phosphate rock	3.4	19.1
Limestone and phosphatic mudstone	5.6	2.8
Phosphatic limestone	2.9	11.4
Mudstone and limestone	1.8	3.2
Phosphate rock	1.4	30.7
Limestone and phosphatic mudstone	3.1	3.5

[1] (39, pp. 24-25).
[2] (39, pp. 30-31).

BECKWITH HILLS DISTRICT

General

The Beckwith Hills (fig. 55) are a north continuation of the Crawford Mountains (Utah) topography into Wyoming. The local relief is roughly 100 to 200 feet in contrast to the +1000-foot relief in the Crawfords. The hills are easily accessible from U.S. Highway 89, and a railroad spur from the Oregon Short Line serves San Francisco Chemical Co.'s phosphate processing plant in the center of the area.

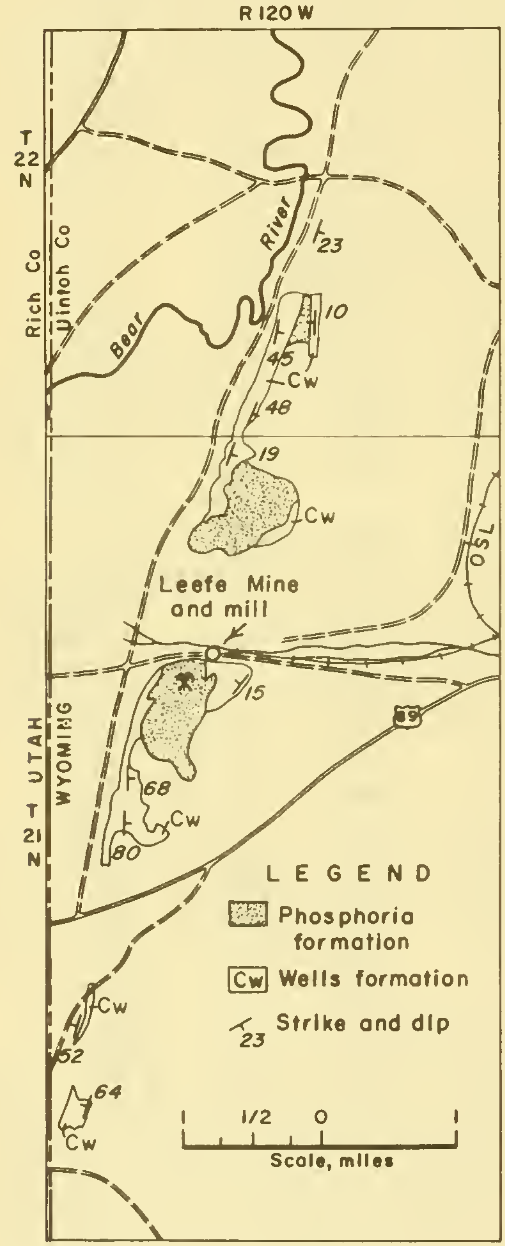

FIGURE 55. - Beckwith Hills (Leefe) District. (Modified from Gale, plate 10.)

The phosphate deposits lie mainly on patented claims, although there are some exposures on public domain in the northern part of the area. Practically all of the phosphate land is controlled by the San Francisco Chemical Co. through either patented claims or Federal phosphate leases.

The geology of the area is characterized by a north-trending synclinal structure in which the Phosphoria formation lies in the trough. This syncline is rather tight on the north but flattens out near the middle of the area; on the south it is presumed to be overturned to the east (<u>20</u>, p. 510).

The Meade Peak member in this area ranges between 150 and 200 feet in thickness. The entire section contains appreciable amounts of phosphate rock, but the richest phosphate zone is at the top. There are comparatively wide areas covered by Wasatch formation and Quaternary sediments. The Phosphoria formation and Meade Peak outcrops are limited by these sediments. The high grade of the upper phosphate zone and its lack of carbonaceous material indicates the well-known pre-Wasatch erosion period, when the carbonaceous material was leached, resulting in a higher grade phosphate zone. The phosphate rock in this area is characteristically white to light gray.

Mining

San Francisco Chemical Co. is the only active mine operator in the Beckwith Hills district. Some underground development was attempted during the early 1900's but was unsuccessful because of the necessity of

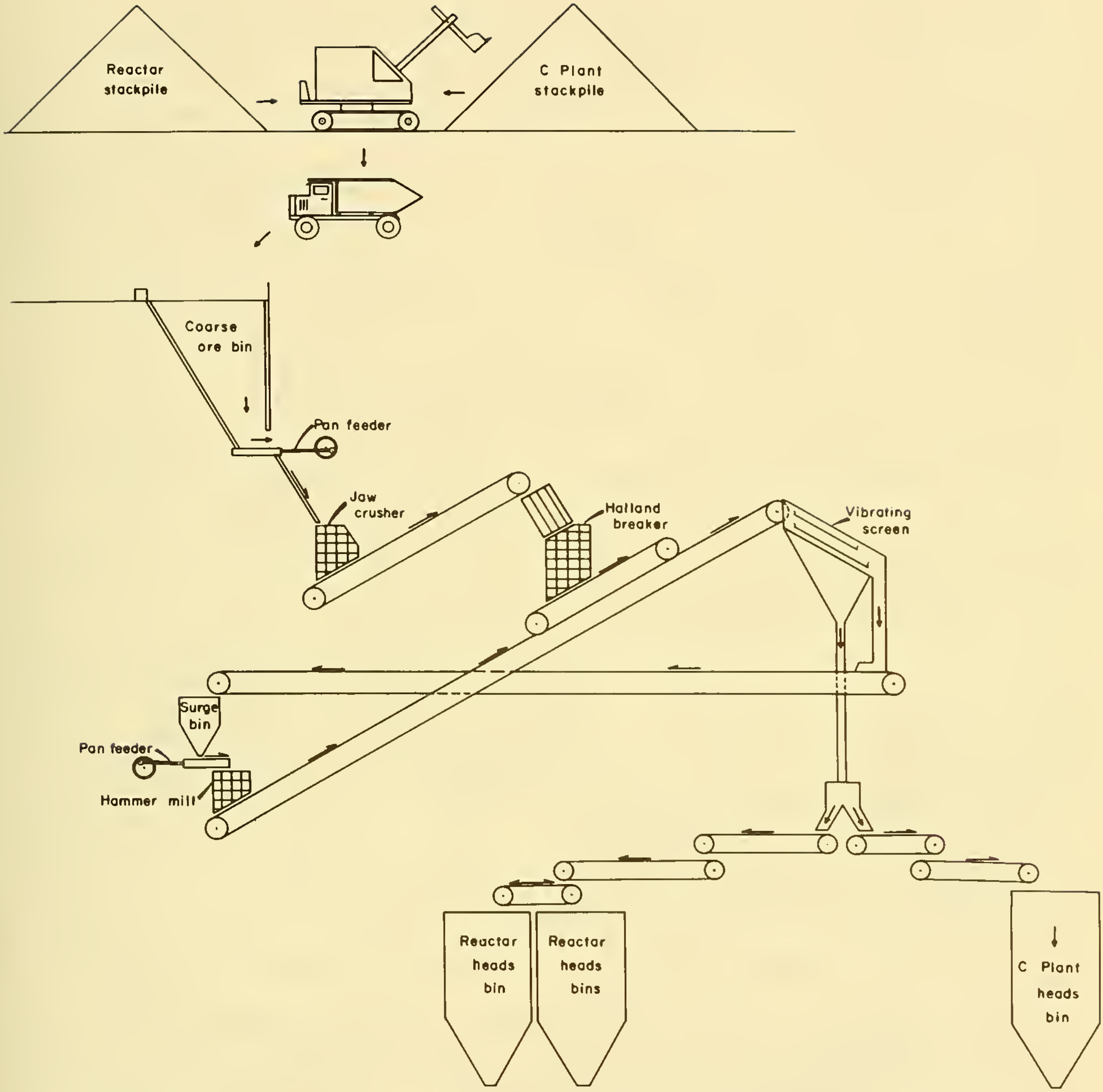

FIGURE 56. - Crushing Plant Flowsheet. *(Courtesy, San Francisco Chemical Co.)*

excessive rock support. San Francisco Chemical Co. started development of the Leefe open pit mine and construction of a beneficiation plant in 1947. Plant facilities consist of primary and secondary crushing units, Raymond mill pulverizing unit, flotation circuits, and fluosolids reactors (fig. 56-59). Total annual capacity is approximately 750,000 tons of acid-grade concentrate that is shipped to basic fertilizer producers in the Northwest and Canada.

The Leefe mine was first developed to recover the upper acid-grade (+32 percent P_2O_5) bed in the Meade Peak member; the plant was modified in 1947 and

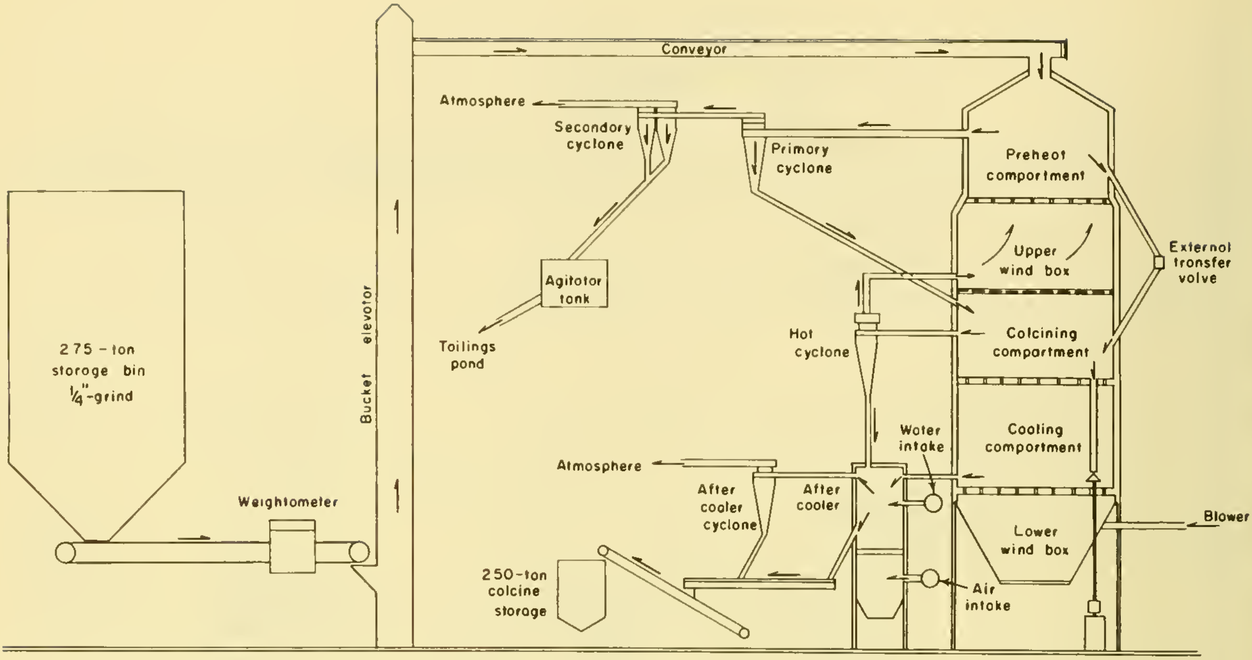

FIGURE 57. - Reactor Flowsheet. *(Courtesy, San Francisco Chemical Co.)*

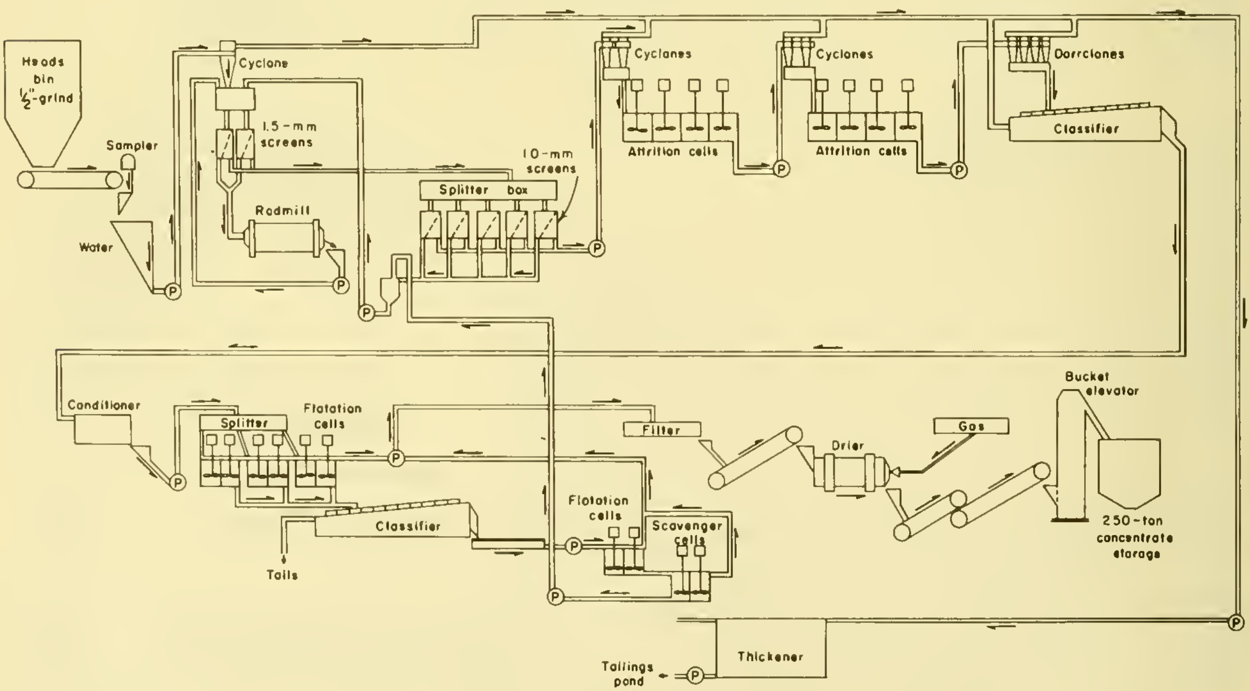

FIGURE 58. - Flotation Plant Flowsheet (C Plant). *(Courtesy, San Francisco Chemical Co.)*

lower-grade phosphatic shales were recovered. The phosphate member crops out on the east and west sides of Beckwith Hills and crosscutting faults separate the deposit into natural mining panels. These panels are drilled to determine

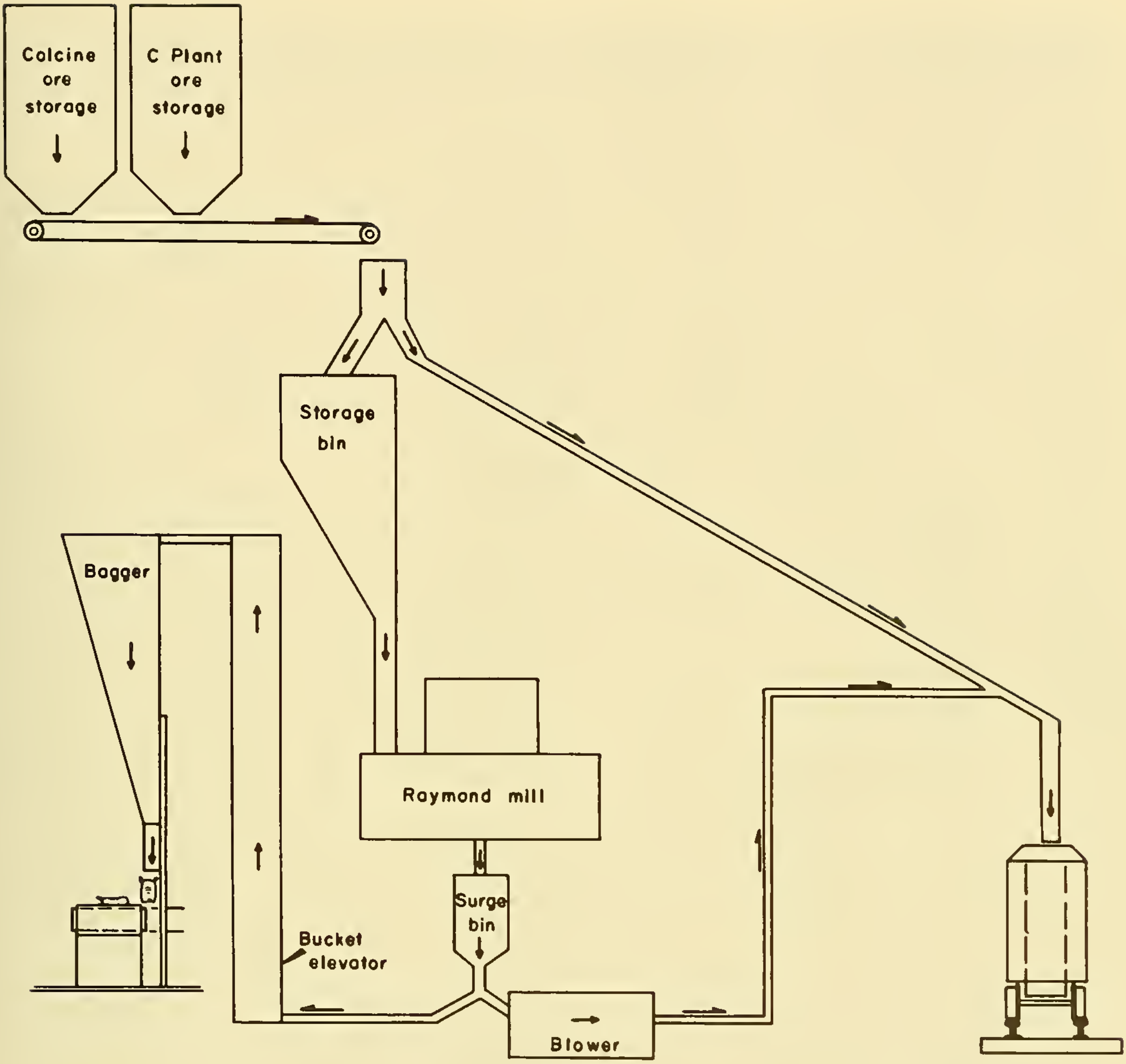

FIGURE 59. - Raymond Mill Flowsheet. *(Courtesy, San Francisco Chemical Co.)*

the relationship between the overburden and the phosphate member; holes are spaced on 200-foot centers (fig. 60). Stripping ratios are determined, and the overburden is removed back to the maximum waste to ore ratio limit. The upper phosphate zone is mined selectively, leaving the lower phosphatic shales for later recovery (fig. 61). All overburden is dumped beyond the phosphate outcrop line to minimize any later ore dilution.

The total thickness of the mining section is about 20 to 23 feet from the top of the hanging wall bed to the bottom of a lower +2-foot high-grade bed. There are four different phosphate and phosphatic shale horizons in the mining section; that is, upper high-grade bed +5 feet, upper phosphatic shale bed +5 feet, second phosphatic shale bed +6 feet, and lower massive oolitic phosphate bed 2 to 4 feet (fig. 62).

FIGURE 60. - Aerial View of Leefe Mine and Plant. *(Courtesy, San Francisco Chemical Co.)*

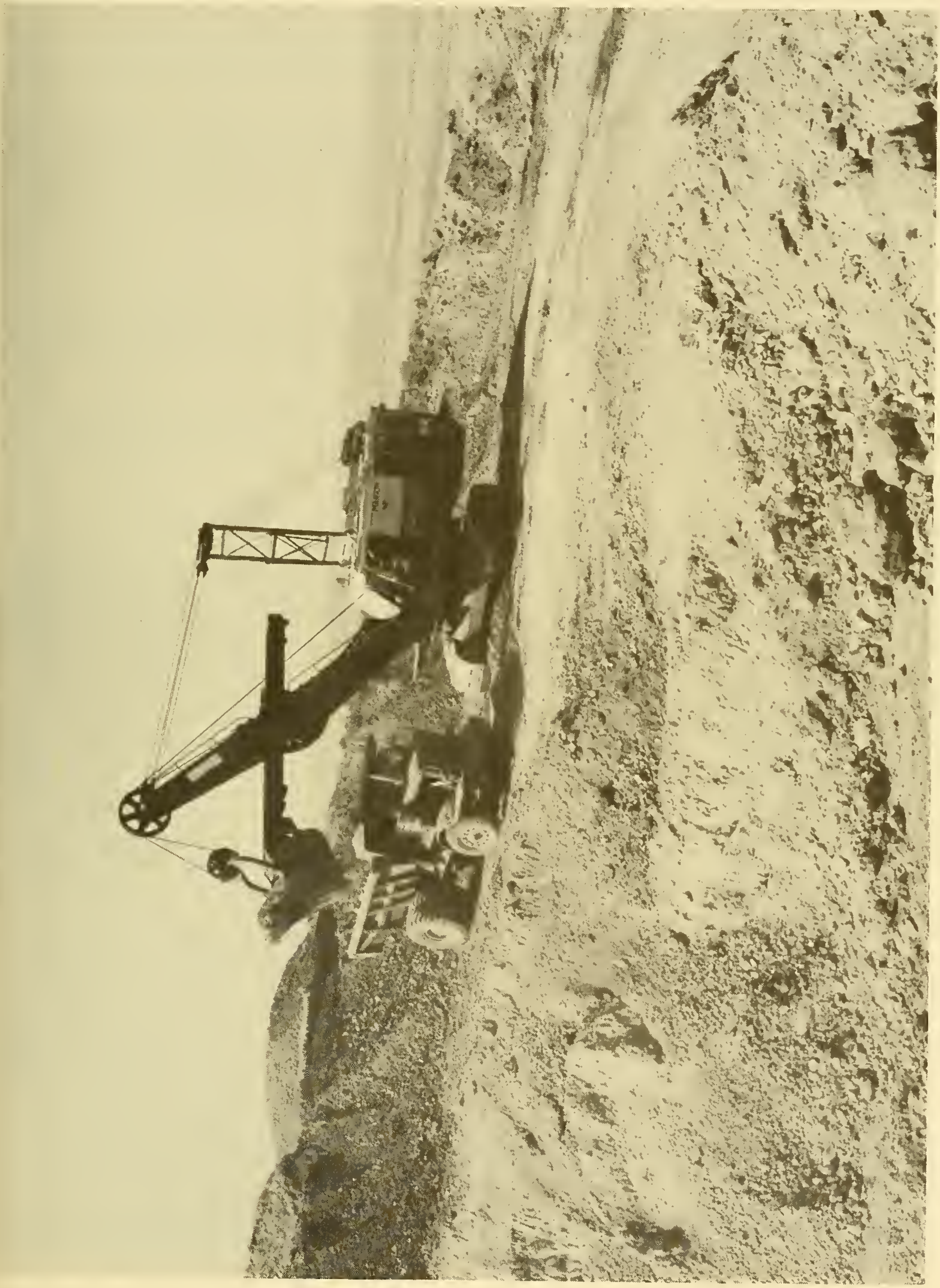

FIGURE 61. - Leefe Mine.

Gale established a resource base of 2.8 million long tons of high-grade phosphate rock in the Beckwith Hills (20, p. 513). This was considered a minimum figure based on a 5-foot bed; probably the 5-foot "A" bed now being mined.

Mining has progressed continuously for nearly twenty years at this locality. Production has been aided by advances in processing technology developed by the company. Further advances in processing and mining methods will undoubtedly be forthcoming and will extend the life of this property for several years.

CRAWFORD MOUNTAINS DISTRICT

The Crawford Mountains extend for about 15 miles in a northerly direction along the eastern border of Utah, with the northern extension of the mountains and the Beckwith Hills projecting into Wyoming (fig. 63).

The mountains rise abruptly from the Bear River Valley to the west and slope more gradually to the east into Wyoming. The local relief is about 1,200 to 1,800 feet.

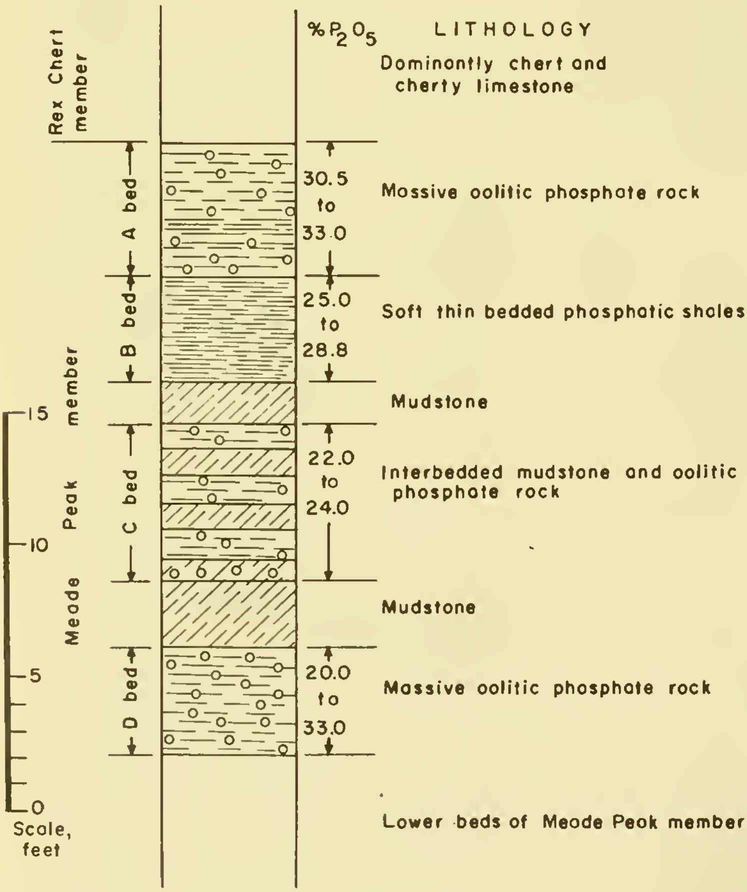

FIGURE 62. - Mining Section, Leefe Mine.

(Courtesy, San Francisco Chemical Co.)

Geology

The beds of the Crawford Mountains are highly folded and faulted. A number of folds are outlined by the Phosphoria formation, but the major structural feature of the mountains is a syncline on strike with the general trend of the mountains. This structure is outlined by the Phosphoria outcrop as mainly a doubly plunging syncline with the beds exposed very near the trough in the north.

The Phosphoria formation in this area has been mapped as an approximate 400-foot-thick unit. This is divided into the lower Meade Peak member (±250 feet), and the upper Rex Chert member which varies from about 125 to 200 feet (42, p. 25). Further studies by McKelvey have placed the Permian sequence here in the realm of influence of the Park City lithology (39, plate 3).

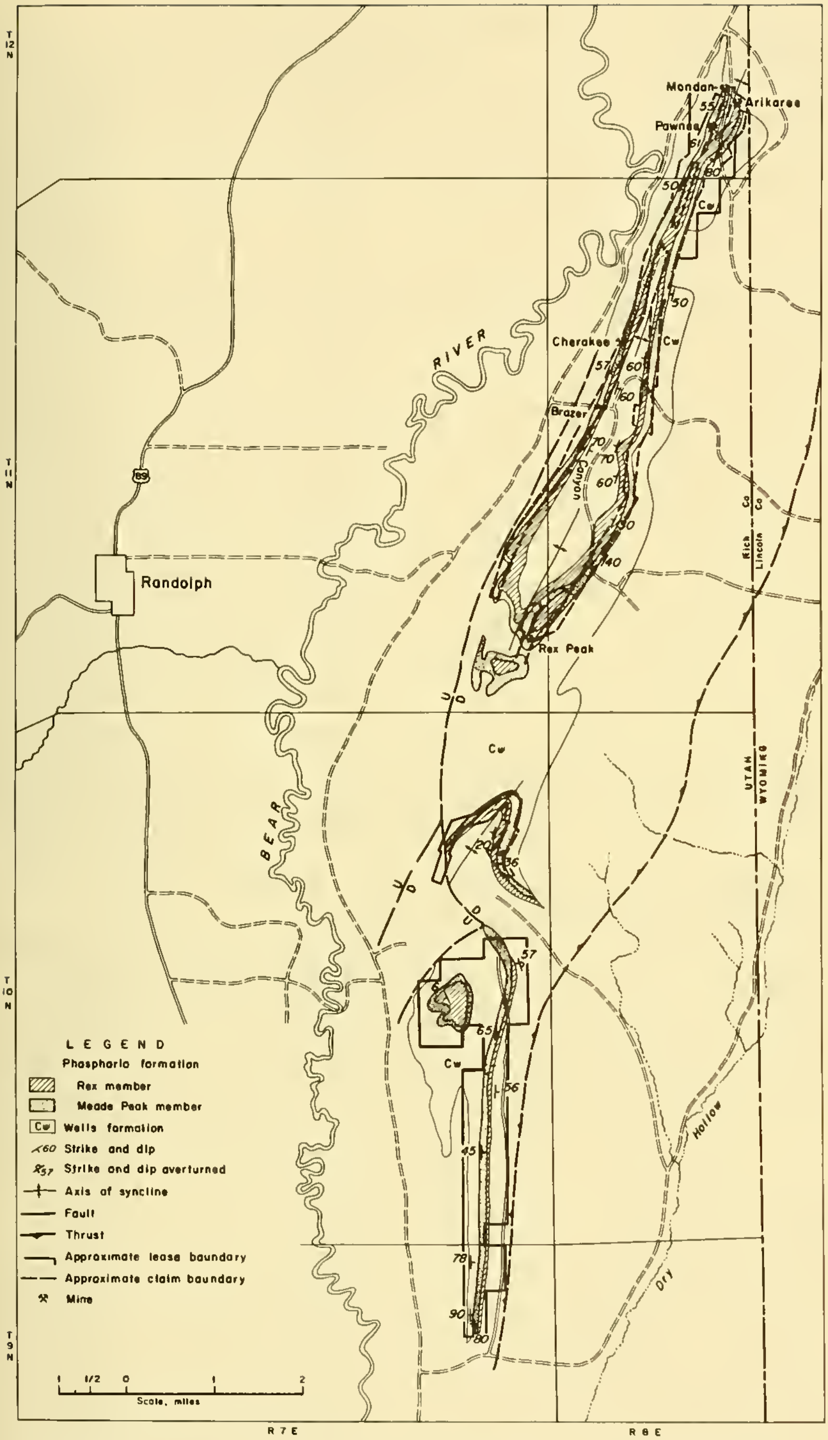

FIGURE 63. - Crawford Mountains District. (Modified from Gale, plate 11.)

In the Brazer Canyon trench (<u>62</u>, pp. 5-15) McKelvey recognizes the basal Grandeur member, the Meade Peak tongue, and two tongues of the Rex Chert that are split by the Franson member. According to this classification, the Grandeur would be a little more than 40 feet thick and the Meade Peak would be approximately 70 feet thick. The overlying Rex-Franson interval was measured at 219 feet in the Brazer trench (<u>55</u>, pp. 6-7).

The total Meade Peak thickness (including the Grandeur member) in the Crawford Mountains ranges from the measured limits of 145 to 212 feet (<u>12</u>, p. 10, <u>61</u>, p. 10). The thickness and grade of the phosphate enrichment zone changes considerably from place to place. In the northernmost part of the range the entire section is phosphatic (table 45). Here a trench exposed 127 feet that analyzed +11 percent P_2O_5 (<u>12</u>, pp. 7-10), with comparatively rich beds near the base and the top. Farther south, the middle part of the Meade Peak becomes relatively lean (tables 46 and 47). At the southern end of the Crawford Mountains the upper phosphatic zone of the Meade Peak was found to contain 8.9 feet of +31 percent P_2O_5 rock (<u>58</u>).

TABLE 45. - Meade Peak section, North Crawford Mountains[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Mudstone	14.4	0.6
Phosphate rock and carbonate rock	3.8	11.8
Phosphate rock	3.2	32.6
Phosphate rock	6.5	26.6
Mudstone	2.8	2.6
Phosphate rock	6.3	23.9
Carbonate rock and mudstone	2.4	0.8
Phosphate rock	1.4	17.3
Carbonate rock and phosphatic mudstone	9.0	3.9
Phosphate rock	1.1	25.6
Mudstone and carbonate	13.6	2.5
Phosphatic mudstone and carbonate rock	14.6	10.6
Phosphate rock	8.2	21.6
Mudstone and carbonate rock	23.1	3.0
Phosphatic mudstone	2.8	11.3
Mudstone	1.0	1.2
Phosphate rock	1.6	20.3
Carbonate rock	1.8	1.4
Phosphatic mudstone	2.7	13.5
Mudstone	1.4	1.5
Phosphate rock	9.2	24.8
Carbonate rock, mudstone, and chert	11.5	5.9
Phosphatic limestone and phosphate rock	2.7	14.3

[1] (12, pp. 7-10).

TABLE 46. - Meade Peak section, upper Brazer Canyon[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Limestone and mudstone	6.6	0.8
Phosphate rock	1.2	21.0
Limestone	2.8	6.2
Phosphate rock	4.7	32.0
Phosphate rock	5.1	26.6
Limestone	2.3	0.9
Phosphate rock	4.9	24.1
Limestone, chert, and mudstone	8.6	2.3
Phosphate rock	1.4	24.9
Mudstone and limestone	6.8	3.6
Phosphate rock	1.6	17.1
Mudstone and limestone	11.1	2.6
Phosphatic mudstone	2.5	10.1
Mudstone and limestone	4.3	5.2
Phosphatic mudstone and limestone	6.2	13.5
Phosphate rock	5.7	20.2
Mudstone, limestone, and chert	34.4	3.6
Phosphatic mudstone and limestone	6.9	10.5
Mudstone	1.5	2.7
Phosphate rock	7.2	21.3

[1] (55, pp. 21-23).

TABLE 47. - Meade Peak section, Brazer Canyon[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Mudstone	42.3	1.2
Phosphate rock	3.5	31.5
Phosphate rock	5.7	26.6
Mudstone	2.9	6.5
Phosphate rock	4.9	25.3
Chert, mudstone, and dolomite	7.7	0.8
Phosphate rock	1.3	25.3
Mudstone	9.8	4.6
Mudstone and phosphate rock	4.1	12.0
Mudstone	16.5	2.5
Phosphatic mudstone	10.6	10.4
Mudstone and limestone	5.3	4.3
Phosphate rock	4.4	18.1
Limestone	1.1	2.6
Phosphate rock	1.9	27.6
Mudstone and limestone	25.2	2.5
Phosphatic mudstone	5.9	10.9
Phosphatic mudstone	8.2	5.6
Phosphate rock	2.1	22.6
Limestone	1.2	1.0
Phosphate rock	5.7	22.7
Limestone, phosphatic mudstone, and chert	42.1	4.9

[1] (55, pp. 6-10).

Mining and Development

The Crawford Mountains have a long history of development that began shortly after the turn of the century. Several mines have operated here intermittently throughout the years; however, the first significant production came in 1954 when San Francisco Chemical Co. began production from the Arickaree, Pawnee, Mandan, Tuscarora, and Emma mines. Later production came from the Bradley and Sioux. J. R. Simplot Co. also mined a small amount of phosphate rock from Rex Peak in 1955.

Operation of the Arickaree, Pawnee, Mandan, Tuscarora, and Emma mines was discussed by Wideman (62). At that time, maximum production was about 30,000 tons per month, most of which was produced in the Arickaree, Tuscarora, and Emma mines. The only mine operating (1964) in the Crawford Mountains is the Cherokee mine on the west face of the mountains and the west limb of the Crawford syncline (fig. 64). Development of this mine began in 1955 and initial production started in 1957. Mine production has increased steadily and workings now extend across the syncline to the Emma-Tuscarora properties, and both limbs of the syncline are under development. In 1964 San Francisco Chemical Co. began driving a drift north from the Brazer Canyon outcrop to develop the Benjamin property, south of the Cherokee. This will increase Cherokee mine production from 2,000 to 3,000 tons per day; the additional tonnage will be handled by the new vertical calciner at the Leefe plant.

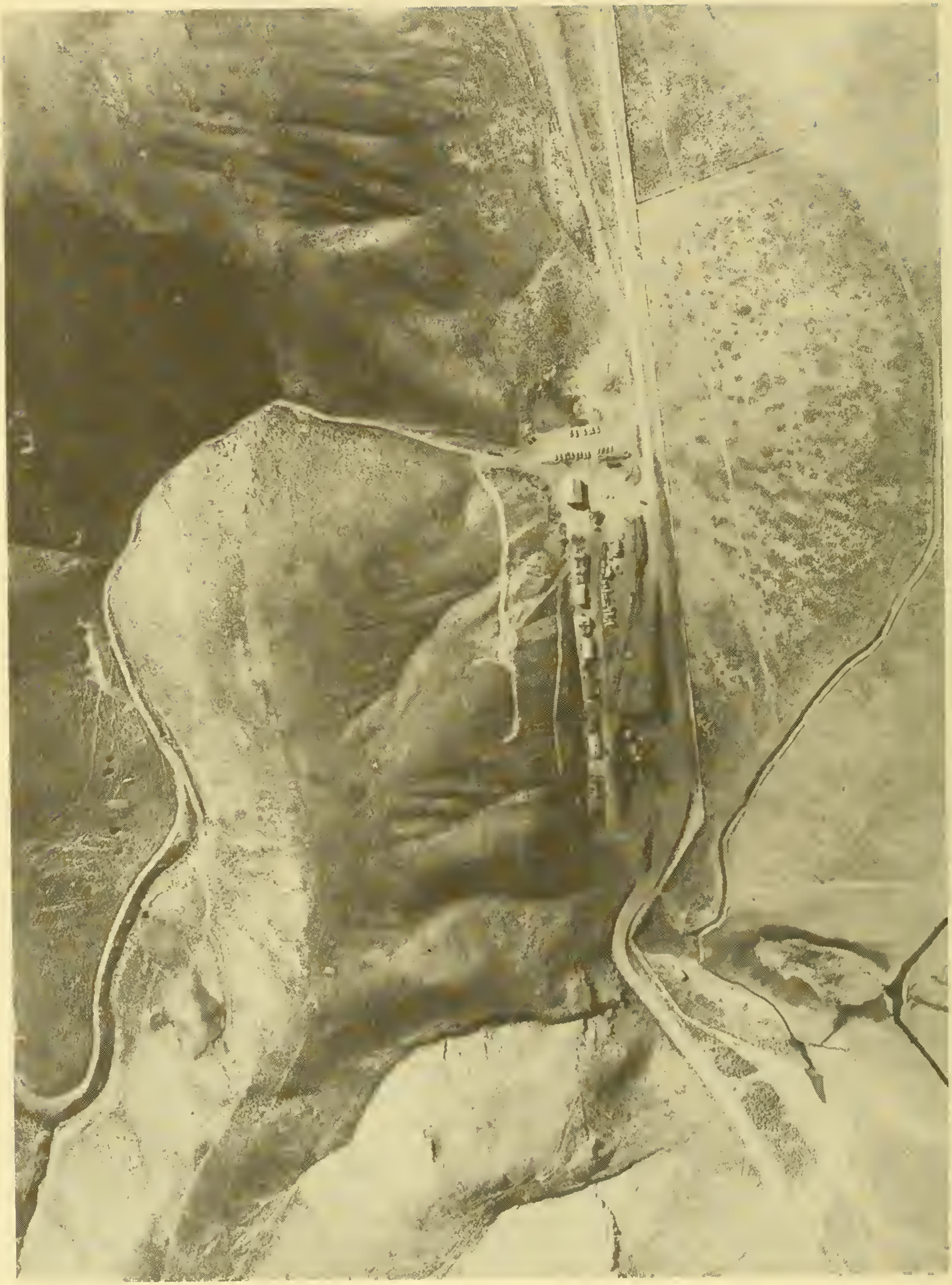

FIGURE 64. - Aerial View, Cherokee Mine. *(Courtesy, San Francisco Chemical Co.)*

The earliest mining operations in the Crawford Mountains considered only the "A" bed (upper high-grade bed) as minable rock. This bed normally varies between 3.5 and 5 feet in thickness and at the time could be shipped as acid-grade for fertilizer production. It lies directly under the Rex chert, which is generally a competent hanging wall. There are, however, places where this rock is fractured or where there is a soft mudstone strata separating the chert from the hanging wall bed. Stull supports and care in drilling and blasting minimizes sloughing and dilution.

Installation of additional beneficiation facilities at Leefe made it possible to recover the bed directly under the "A" bed. This zone, the "B" bed, usually is from 1 to 2 feet thicker than the upper bed and ranges from 24 to 31 percent P_2O_5. A third ore zone underlying the bed ranges between 5 and 6.5 feet and usually varies between 18 and 24 percent P_2O_5. The "A" and "B" beds have been traced to the southern end of the mountains where they make up a zone of nearly 9 feet of +31 percent P_2O_5 rock on the surface; however, it can be assumed that this grade decreases at depth.

Sublevel stoping and modified room and pillar mining methods are used at the Cherokee mine. The mine is developed by a 2,200-foot adit, and more than 6,000 feet of drifts, crosscuts, and raises block out ore reserves on both limbs of the syncline. The thick mining section made it possible to use sublevel stoping to good advantage and a large part of the mine has been developed with this in mind. More recently, a modification of the room and pillar method has been used. Long holing and block caving were tried with some success, but cost was high and the recovery was not as good as expected.

Resources and Potential

The Crawford Mountains have long been of interest to the phosphate industry. The deposits in these mountains were among the first to be discovered in the Western field, and exploration commenced shortly after the turn of the century. Activity in this area and other adjacent areas in Idaho and Wyoming prompted studies that led to the first phosphate land withdrawal pending classification in 1908. By this time, however, most of the phosphate outcrops were covered by mining claims. Many were subsequently patented and some were abandoned. The areas either not covered by mining claims or abandoned, however, have since been leased by the major land holders of the area (see fig. 63).

As previously mentioned, the phosphate resources were estimated to be 90 million long tons in 1909 and 60 million long tons in 1942. The former figure considered a 5-foot bed of high-grade rock, whereas the latter estimate uses a 3-foot thickness in part of the outcrop. In both these estimates the beds were taken to a 2,000-foot depth.

The present study indicates potential phosphate resources as shown in table 48. These estimates are calculated on total in-place rock and do not consider the blocks that have been mined out; neither do they allow for mining loss or losses due to structural complications.

TABLE 48. - Phosphate rock resources in the Crawford Mountains (million short tons)

Grade, percent P_2O_5	Above drainage entry	100 feet below
+31...........................	32.7	5.8
+24...........................	122.3	22.0
+18...........................	217.1	38.1
+10...........................	340.5	79.2

In view of recent developments in the Crawford Mountains, it is easy to assume an optimistic outlook for the area. The expansion of the Cherokee mine to the upper levels, as well as the underground exploration completed by FMC Corp. in upper Brazer Canyon in 1964, are most certainly an indication of growing interest in the area. Undoubtedly, it will be only a matter of time before other major landholders or lessors institute some form of exploration activity that will eventually lead to development.

The Crawford Mountains are well situated with respect to transportation facilities. The deposits on the northern end are only a few miles from the railhead at Sage, Wyo. The southern end is accessible from either Sage (about 20 miles) or Evanstone, Wyo. (about 40 miles). The recent ruling by the Utah Highway Commission allowing a 60-ton gross vehicle weight brings the south Crawford Mountains phosphate deposits closer to commercial status. It is now conceivable that rock or concentrates could be trucked to Evanston or Sage.

UINTA MOUNTAINS DISTRICT

General

The Uinta Mountains (see fig. 3) extend about 130 miles into northeastern Utah and several miles into western Colorado. The topography of the mountains is extremely rugged in the central part; on the flanks where the Phosphoria formation crops out, the topography is more of the dip slope and bench type. In these areas, however, there is vertical relief of as much as 2,000 feet where some of the streams are incised into the gently dipping sediments (fig. 65).

There have been a number of applications for phosphate prospecting permits and leases in the Uinta Mountain district, both on the north and south flanks of the range. There is an area on the north flank of the mountains where the Geological Survey found 6.1 feet of +24 percent P_2O_5 rock.

By far, the most important phosphate occurrence is in the southeastern part of the range north of Vernal where the majority of the exposures are covered by patented claims originally owned by the Humphreys Phosphate Co. These claims were purchased by the San Francisco Chemical Co. who are now mining and operating a 500-ton-per-day flotation plant on the property. Access to the central part of the mountains is quite difficult; however, existing secondary roads provide easy access routes to most of the phosphate exposures.

FIGURE 65. - Typical Topography in the Vernal Field.

Previous Studies

The Uinta Mountains have been the object of several geologic studies. These mountains have, for years, been attractive to geologists and paleontologists because of the impressive outcrop character of the sediments and the abundant vertebrate fossils located in the vicinity of Dinosaur National Monument on the southeastern flank of the mountains. An exposed section from the Cretaceous Frontier formation to the Precambrian can be seen from the highway and from a gravel road crossing the eastern end of the Uinta arch. The outcrops are so prominently displayed that they are marked by road signs showing formation name and age.

Geologic studies of the Uinta Range date from 1876 and constitute a voluminous amount of work, both economic and academic, in the various geological subjects and locations. The earliest report on the phosphate resources of the Uinta Range was by Schultz (50). The mountains were further studied with respect to phosphate in 1939 (63), 1942 (64), and 1957 (8).

Several preliminary geological maps were incorporated into a later report on the Uinta River-Brush Creek areas (30). This work is important in that it covers the only area of commercial phosphate occurrence in the Uinta Range district, with resource estimates that are contiguous with the scope of the present work. Also in this area, the Humphreys Phosphate Co. explored their claims quite extensively with pits and tunnels; however, results of this work are not available for publication.

Geology

The Uinta Range anticline is a large, simple structure associated with many parallel and transverse faults and folds; the Uinta thrust zone on the north flank of the mountains is extremely complex. The more extreme structures, however, do not greatly affect the Paleozoic and Mesozoic sediments on the flanks. These beds reflect a more simple structure in dipping consistently to the north and south at relatively low attitudes. There are certain areas of steep dip and faulted Paleozoic strata, but the majority of the Phosphoria outcrops are flat lying and affected by small scale normal faults. North of Vernal, the Meade Peak member dips to the south at about 8° and locally as much as 25°.

One faulted area, called the south flank fault zone, (30, p. 124) affects the Meade Peak outcrops to some extent; however, this is an area of low phosphate potential. The Meade Peak member is also involved in the Uinta fault zone on the north flank of the mountains, but here there is also a low-phosphate economic potential. On the south flank of the mountains the south-dipping Paleozoic and Mesozoic beds are affected by several transverse south-plunging anticlinal noses and complimentary synclines. These features are very gentle, and normally only change the direction of the regional dip by a few degrees.

The age of the rocks exposed in the Uinta Mountains range from Precambrian to Tertiary and large areas in the central and western parts are covered by glacial deposits. The most distinctive Tertiary unit is the Bishop conglomerate that covers a large area of phosphate near Vernal. This formation overlaps the Park City beds in all areas in this part of the field.

The phosphatic interval in the Uinta Range, as in the rest of the Western field, is in the Meade Peak member which lies directly on Weber sandstone in the southeastern part of the range. To the west and on the north flank, the Grandeur member develops as the basal unit of the Park City beds.

The Meade Peak member has been measured as nearly 100 feet thick in the western part of the Uinta Range, with a negligible phosphate content (12, pp. 20-21). The member thins to the east, and the easternmost measured section on the north flank of the range is about 43 feet thick (12, p. 23); the member thins to approximately 20 feet in the Uinta River-Brush Creek area. There appears to be a relation between thickness and total content of phosphate since the thinnest sections contain the most phosphate enrichment.

The Franson member, usually split by the Mackentire tongue, overlies the Meade Peak member in the Uinta Range. The Franson member is dominantly of carbonate-chert lithology, whereas the Mackentire tongue is mainly a siltstone-sandstone-shale sequence. The Mackentire, at its type locality, is nearly 100 feet thick (38, p. 35); to the east, at Split Mountain, it replaces the

Franson member as the top unit of the Park City formation. These two units are well known in the Brush Creek area where the Meade Peak phosphate member is being mined. They are both about 30 feet thick and the upper (Mackentire) tongue is considered the "soft cap;" the lower (Franson) member is called the "hard cap," and must be blasted before stripping.

There are two areas in the Uinta Range where the Meade Peak can be considered a potential resource. The most important is the Vernal field where roughly 30,000 acres of Park City beds crop out between Ashley Creek and the end of the exposures at Brush Creek. About one-half of this area is now covered by patented claims. The other potential area is an exposure on the north flank of the range near Horseshoe Bend, where about 6 feet of +24 percent P_2O_5 rock was found (12, pp. 22-24).

In the Vernal field, the Meade Peak has been trenched and sampled at three localities. Kinney has established a weighted average of phosphate content for this area at 17.8 feet, averaging 20 percent P_2O_5 (30, p. 168).

Virtually all of the commercially important phosphate resources of the Uinta Range are located in the Ashley Creek-Brush Creek area where the Park City formation crops out over about 24,000 acres. A total of over 1.8 billion tons of +18 percent P_2O_5 rock has been estimated above stream level from Ashley Creek east to the end of the outcrop (30, p. 172). Throughout the rest of the flanks of the Uintas, the Phosphoria crops out for a total strike length of approximately 75 miles. Only a small part of this length (on the north flank of the range at the eastern end of the outcrop) contains any appreciable phosphate.

Vernal Field

The Vernal field (figs. 66 and 77) consists of a comparatively great expanse of phosphate outcrops dipping off the south flank of the Uinta Mountains at attitudes that normally range between 6° and 10°; local dips are as much as 25°. There are a few faults in the main part of the field but these are simple, normal faults with small displacements which do not appreciably affect the Meade Peak member. Toward the western part of the area, the faulting becomes more severe as it approaches the large shear area of the South Mountain fault zone. This zone becomes fairly intense between Ashley Creek and its Dry Fork. The severity of the faulting displaces the Park City into a series of small fault slices for a considerable distance before the formation is covered by the Bishop conglomerate of Mosby Mountain.

The Meade Peak member varies in thickness between the approximate limits of 18 to 22 feet in the Vernal field and, for the most part, it rests on the hard quartzite and sandstone of the Weber formation. The Meade Peak is a fairly hard unit, although the coherency is mainly attributed to chert, carbonates, and mudstone within the member. These beds are generally of lower phosphate content and are interbedded with softer zones of higher phosphate content. Because of the relative thinness of the individual beds within the member, it appears unlikely that selective mining will be used. Kinney (30, p. 168) has weighted the sample data from three trenches in the Vernal field

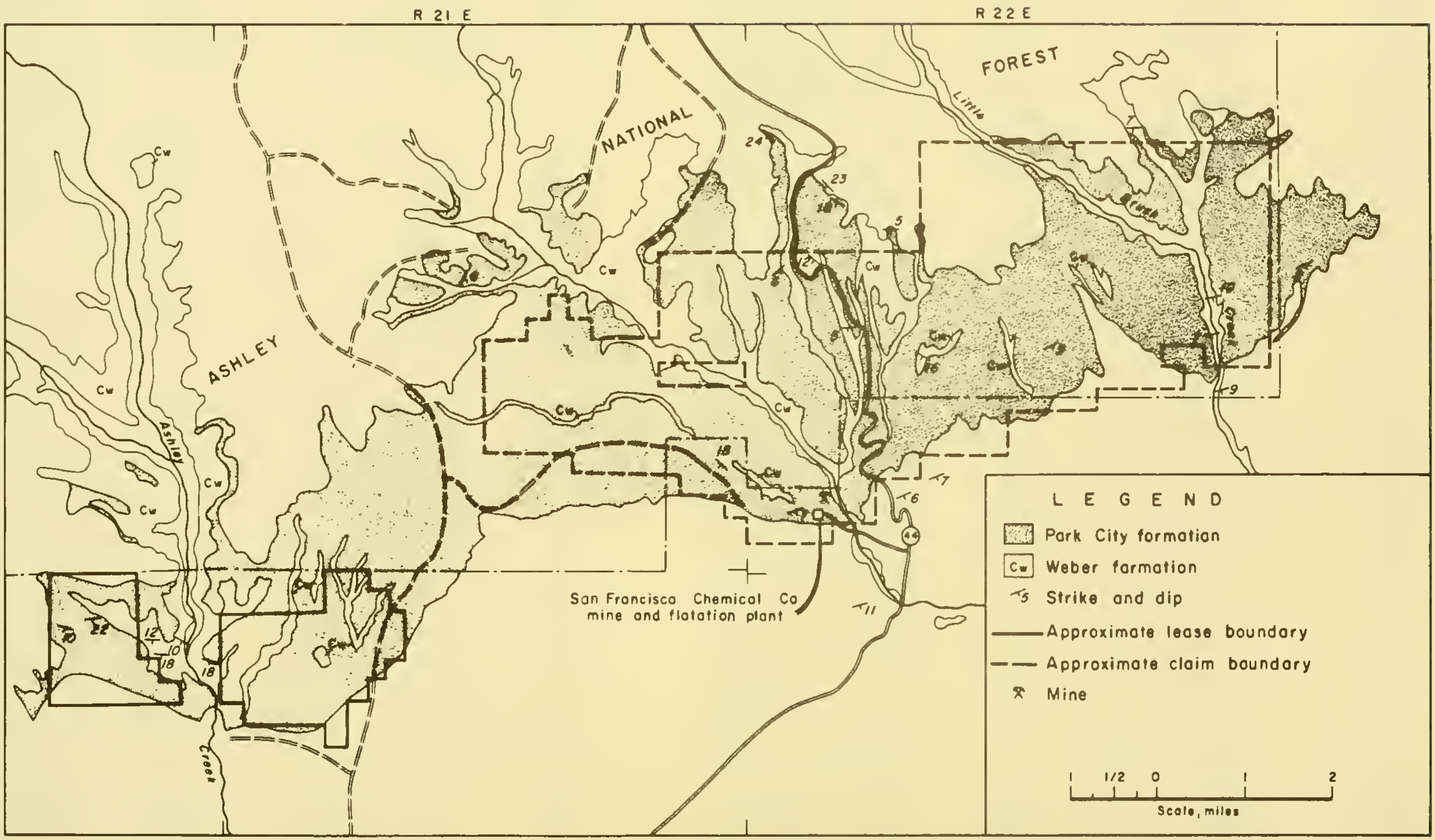

FIGURE 66. - Vernal Field, Eastern Part. (Modified from Kinney, plate 1.)

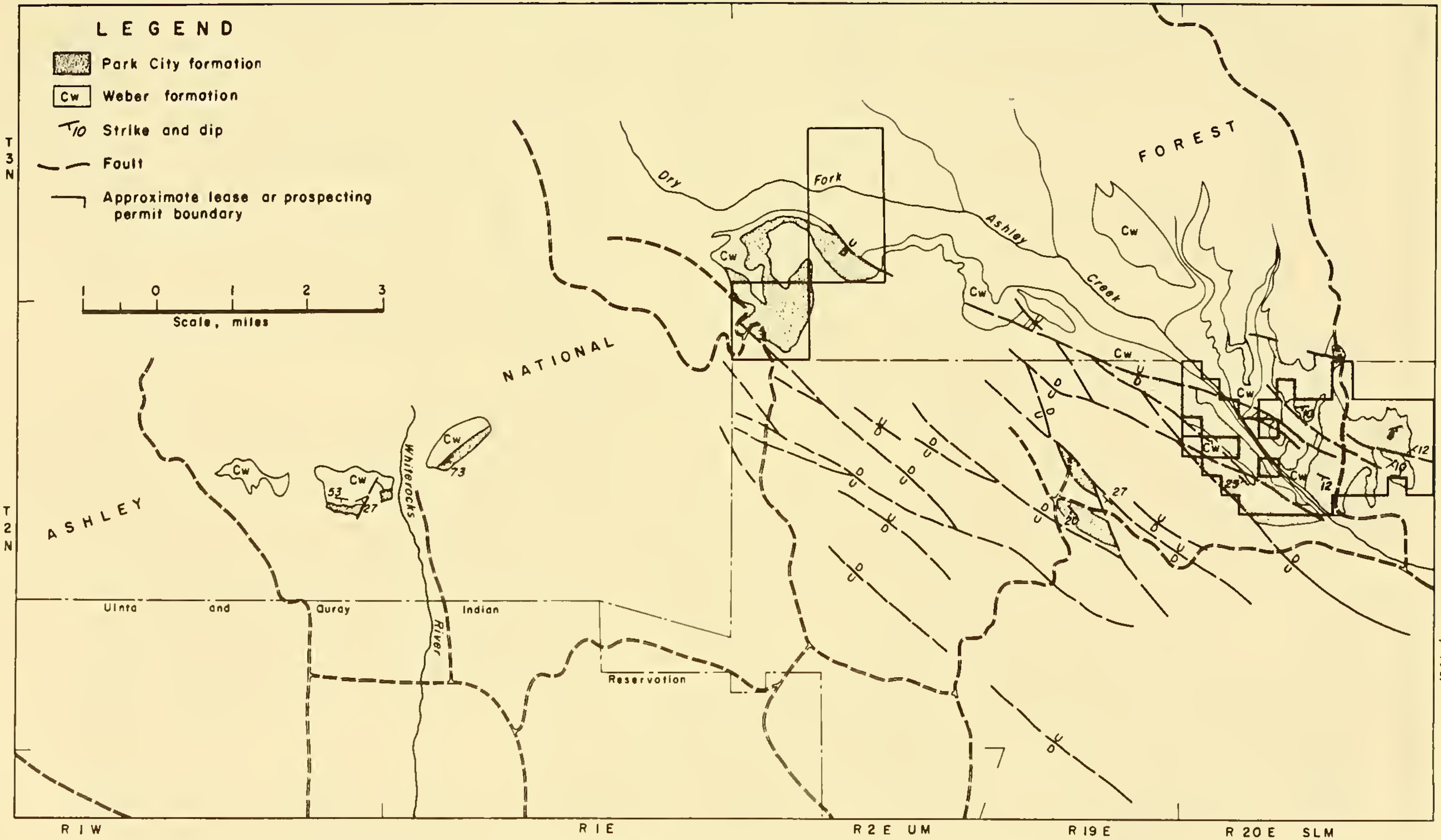

FIGURE 67. - Vernal Field, Western Part. (Modified from Kinney, plate 1.)

as shown in table 49, which illustrates the increase in grade of P_2O_5 from west to east.

TABLE 49. - Meade Peak thicknesses and grades, Vernal field

Sections	Thickness, feet	Weighted average grade, percent P_2O_5
Rock Creek Canyon (adjacent to Ashley Creek)....	16.85	16.4
Brush Creek Gorge..............................	19.70	20.5
Little Brush Creek.............................	16.90	23.0

Total resources in the Vernal field computed by Kinney are shown in table 50 and represent the area from Ashley Creek east to the end of the outcrop. The grade of the Meade Peak member decreases at Ashley Creek (Rock Creek Canyon) to a point where no beds more than 3 feet thick can be placed in the +18 percent P_2O_5 category. When weighted with adjacent parts of the field, however, the overall grade is 20 percent P_2O_5. Thus, a total of more than 1.8 billion tons of rock are estimated for the above area. In line with the grade cutoff of the present study, this can be further divided into +18 percent and +10 percent (+16 percent in this case) P_2O_5 rock, based on sampled sections near Ashley Creek and at Brush Creek. There is roughly 9,500 acres of outcrop of the Park City outcrops and another 4,000 acres to stream level covered by later formations in the latter areas. Assuming the area of influence of grade in each section is one-half the total area between the two drainages, then each block would contain 4,750 acres of outcrop area and another 2,000 acres of bed area to stream drainage level. The total block also contains about 250 acres of bed area for each 100 feet of vertical depth below drainage level. Resources for this area are shown in table 51.

TABLE 50. - Summary of phosphate rock resources, Vernal field[1] (million short tons)

Location	Overburden, feet			100 feet to stream level	Stream level to 1,000 feet below	Total resources
	-43	+43-78	+78-100			
T 3 S, R 20 E......	17.2	16.9	21.8	21.4	76.3	153.6
T 2 S, R 21 E......	91.8	140.7	307.0	85.0	9.7	634.2
T 3 S, R 21 E......	19.8	21.7	77.0	112.5	183.2	414.2
T 2 S, R 22 E......	136.7	220.0	366.0	56.2	266.0	1,044.9
T 3 S, R 22 E......	-	-	-	-	36.2	36.2
T 2 S, R 23 E......	3.9	8.2	21.2	80.0	83.5	196.8
Total...........	269.4	407.5	793.0	355.1	654.9	2,479.9
Cumulative total	269.4	676.9	1,469.9	1,825.0	2,479.9	-

[1]Percent P_2O_5 varies between 16.4 and 23.0.

The area from Brush Creek to the end of the outcrop at Little Diamond Mountain contains approximately 12,500 acres to drainage level. Roughly 8,000 acres lie in outcrop area, and the remaining 4,500 acres are covered by later formations. Also, there are approximately 2,100 acres of outcrop area and another 1,300 acres to drainage level east of Little Brush Creek.

TABLE 51. - Phosphate rock resources between Ashley Creek and Brush Creek (million short tons)

	Outcrop	Above drainage entry	100 feet below
Brush Creek Block (+18 percent P_2O_5)........	346.2	492.0	9.1
Ashley Creek Block (+16 percent P_2O_5).......	297.0	422.1	7.8
Total..................................	643.2	914.1	16.9

Assuming that the area of influence of the Brush Creek (19.7 feet, 20.5 percent P_2O_5) and Little Brush Creek (16.9 feet, 23.0 percent P_2O_5) sections is for each half of the confined area and the area of influence of the Little Brush Creek section extends to the end of the outcrop on the east, the resources for this part of the field would be as shown in table 52.

TABLE 52. - Phosphate rock resources between Brush Creek and Little Diamond Mountain (million short tons)

	Outcrop	Above drainage entry	100 feet below
Brush Creek Block (+18 percent P_2O_5)........	215.0	331.6	11.2
Little Brush Creek Block (+23 percent P_2O_5):			
West..................................	184.5	284.5	9.6
East..................................	131.3	212.6	8.7
Total..................................	530.8	828.7	29.5

Between Ashley Creek and its Dry Fork, the Park City formation crops out over an area of 2,000 acres with another 3,000 acres of bed area to drainage level. About half of this was included in Kinney's estimates as the part of the outcrop that is not visibly affected by extensive faulting to the west. The other half, or the part lying in the Dry Fork drainage area west to Mosby Mountain, was not included because of complex structure and lack of grade information. However, in estimating resources for the entire Vernal field for this study, the outcrop area between Ashley Creek and its Dry Fork is included.

From the divide between Ashley Creek and Dry Fork to the end of the outcrop at Mosby Mountain, there are roughly 3,000 acres of Park City formation lying mainly in isolated fault blocks. About 1,800 acres of this are west of Dry Fork, and the remaining 1,200 acres are on the east side of the Creek. The nearest check point for grade is at Mackentire Draw, about 45 miles west of Ashley Creek. A total of 11.7 feet of rock containing 14.1 percent P_2O_5 was found in this trench (55, p. 32). The overall grade of the same interval decreases by about one-third from the Little Brush Creek trench to Ashley Creek. A definite trend in grade can be seen from these relationships; however, the magnitude of the change cannot be reliably calculated at any locality. Until more stratigraphic information is obtained in the western margin of the field, only an estimate of grade and thickness in the faulted section east of Ashley Creek can be made. For this study, an arbitrary figure of 12 feet of +16 percent P_2O_5 is used.

FIGURE 68. - Bishop Conglomerate Bench Overlying the Park City Formation (Foreground), Vernal Field.

Using these assumptions, the phosphate resources of the faulted western margin of the Vernal field would be:

	Million tons
East of Dry Fork.................	52.8
West of Dry Fork.................	79.2

Other phosphate resources in the Vernal field occur beneath the Bishop conglomerate, particularly in the Little Diamond Mountain area (fig. 68). As stated by Kinney, the Meade Peak may be channeled to a great extent under the relatively unconsolidated sediments of the Bishop conglomerate, thus making a resource estimate impractical (30, p. 70). However, an approximation of the amount of phosphate rock theoretically overlain by the Bishop conglomerate can be made. From Mosby Mountain to Little Diamond Mountain, the total length of the Bishop-Park City contact is about 54 miles. Of this length, the particular grade influence areas would contain the following lengths:

	Miles
Trench area:	
Little Brush Creek....................	17
Brush Creek...........................	15
Ashley Creek..........................	12
Faulted area east of Ashley Creek.......	10

For every 100-foot updip in the Meade Peak member (assuming that the member is not eroded) total resources would be:

	Million short tons
Little Brush Creek trench area (16.9 feet, +23 percent P_2O_5)......	1.3
Brush Creek trench area (19.6 feet, +18 percent P_2O_5)......	1.1
Ashley Creek trench area (16.9 feet, +16 percent P_2O_5)......	1.1
Faulted area east of Ashley Creek (12 feet, +16 percent P_2O_5)........	0.5

The Park City formation crops out for a short distance on the Whiterocks River west of Mosby Mountain. The outcrop dips steeply to the south and extends for about a mile on each side of the river, although it is covered in part by later Tertiary sediments on the west side. This section has been examined and sampled by Williams (63, pp. 13-14). In that study, the trench exposed a 6-foot bed of 19.95 percent P_2O_5; however, this bed also contained 1.2 feet of barren mudstones that were not included thus adjusting the P_2O_5 content for the 7.2-foot interval to about 16.6 percent. There is no topographic information available for this particular area, so the average above-drainage relief is estimated as 200 feet. The resources then estimated for the +7-foot bed of +16 percent P_2O_5 rock would be roughly 1 million tons above drainage level, plus 700,000 tons for every 100 feet vertically below drainage.

Mining and Processing in the Vernal Field

In the mid-1950's, San Francisco Chemical Co. became interested in the 92 patented claims on phosphate land north of Vernal owned by the Humphreys Phospate Co. An exploration program and metallurgical testing proving the feasibility of a mining and processing operation led to the purchase of these claims in 1959. The character of the deposit, both mineralogically and geographically, presented several problems. The phosphate rock occurs in a ±20-foot zone with an overall grade of 10 to 22 percent P_2O_5, and the nearest market outlet is over 200 miles at Garfield, Utah. In order to meet the market requirements, the rock at Vernal must be upgraded to +31 percent P_2O_5 and shipped by truck the entire distance. The mine and plant are located roughly a mile apart in gently dipping topography (fig. 69).

In 1960, plant construction and mine development began and production started in 1961. The plant was originally rated at approximately 200,000 tons of +31 percent P_2O_5 concentrate per year (fig. 70).

The mine operation is relatively simple because the phosphatic section (Meade Peak), underlain by the hard Weber quartzite and overlain by the Franson member of the Park City formation, is well delineated. The dip is about 8° to 10°, and there is very little faulting. The operation consists of scraping the soft overburden (soil and Mackentire tongue), blasting and removing the hard overburden (Franson member), and blasting and loading the ore for transport to the plant (fig. 71).

FIGURE 69. - Vernal Mine Area.

Beneficiation consists of crushing and grinding, classification, and flotation (fig. 72). In the crushing operation it was found advantageous to discard the 1/4- to 3/8-inch fraction which is nearly all hard, barren chert, and which makes up about 2 percent of the total volume of feed.

Size classification is very important in all phosphate beneficiation operations and overgrinding will tend to break the oolites, resulting in sliming and a loss in P_2O_5. Proper grinding and desliming prior to flotation will remove silts and clays with a corresponding upgrading of the product. Flotation will further upgrade the product to an acid-grade concentrate. Experimental work is underway to determine the feasibility of using the Hollingswoth air cells to eliminate fines produced by attrition in the conventional sub-A cells.

The potential of the Vernal phosphate field at the present time can be viewed optimistically. The latest development in this area is the San Francisco Chemical Co.'s planned $17 million expansion of the Vernal facility to produce a fertilizer product. This decision was mainly the result

FIGURE 70. - Vernal Mine.

FIGURE 71. - Vernal Beneficiation Plant.

of Utah State legislative action allowing a maximum load limit of 60 tons on State roads under certain conditions.

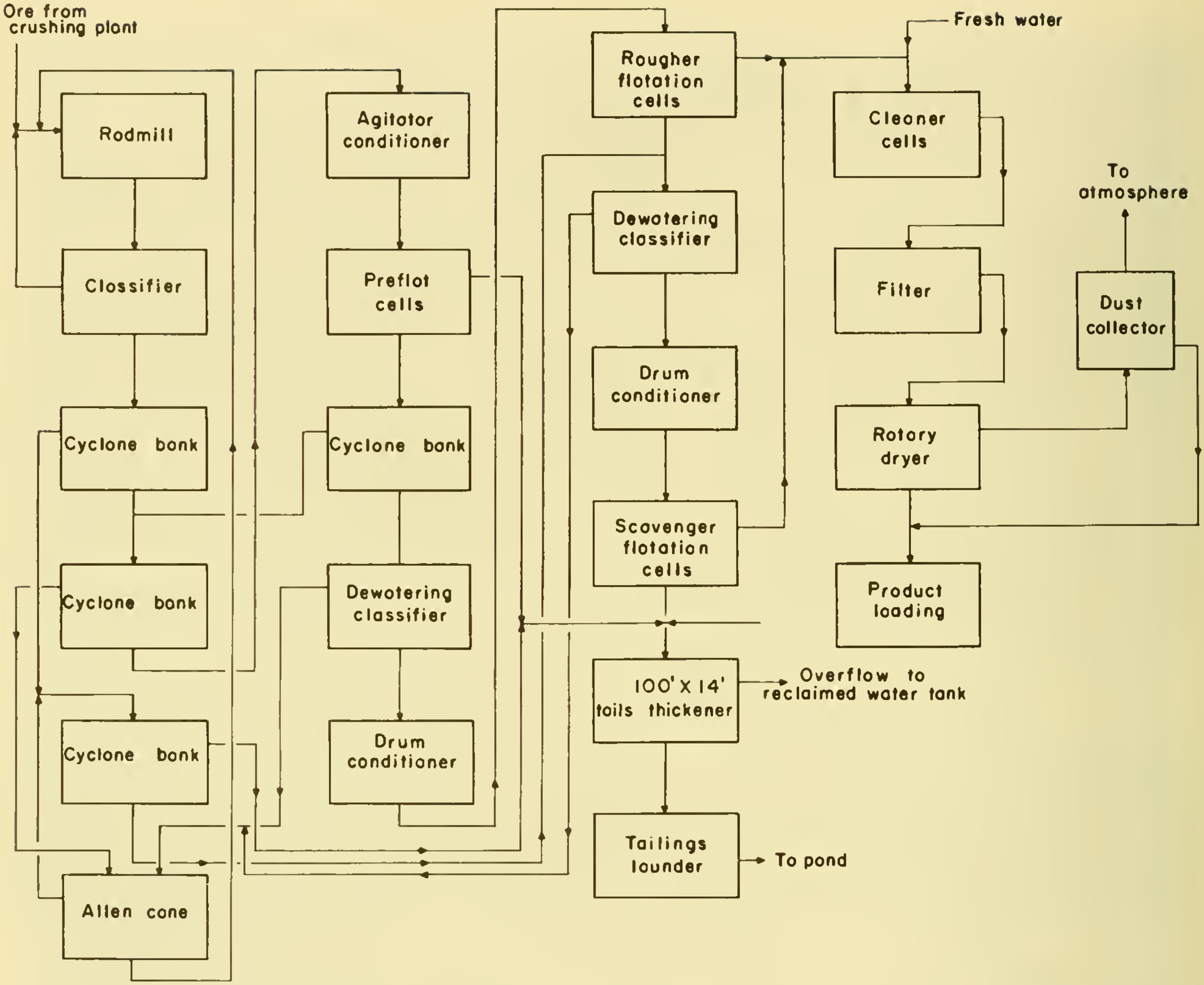

FIGURE 72. - Vernal Plant Flowsheet. *(Courtesy, San Francisco Chemical Co.)*

The present plant facilities have been considered as a pilot type operation; however, the planned expansion indicates that the system has been successful. The potential of the area, then, can be assumed as comparatively great. The Vernal field is, undoubtedly, the largest single body of phosphate rock in the Western field. It would appear that San Francisco Chemical Co. controls about 500 million tons of phosphate rock. In view of the developments previously mentioned, the above figure can be classed as commercially available reserves at present standards.

Western Uinta Range

The Park City formation is exposed for about 40 miles on the western end of the Uinta Range in a discontinuous outcrop pattern (fig. 73). Comparatively widespread areas on the north flank of the range are covered by Quaternary glacial deposits. According to available data, only two areas, both on the eastern end of the south flank, contain potential phosphate deposits.

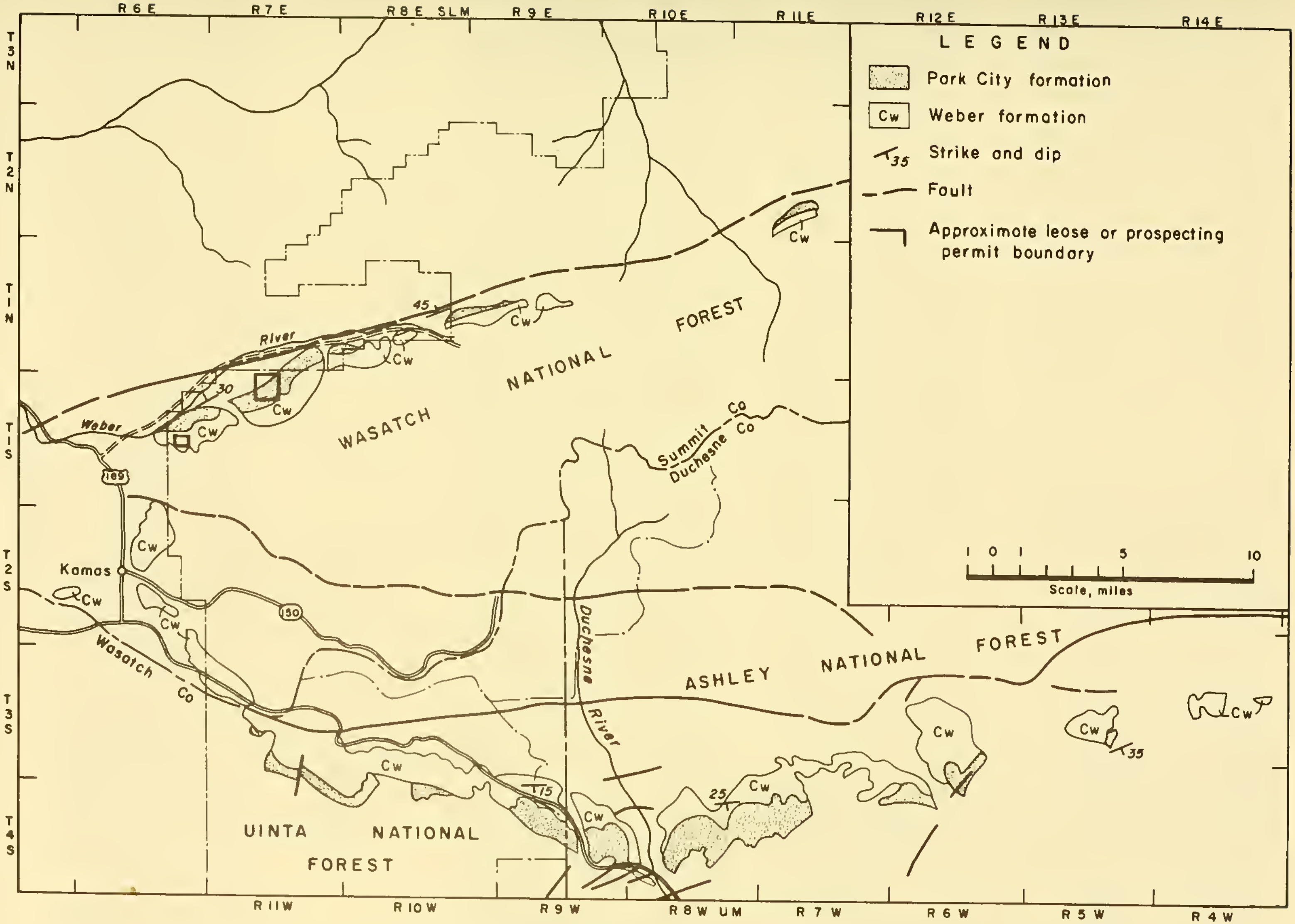

FIGURE 73. - Western Uinta Range. (Modified from Stokes.)

In Mackentire Draw, a tributary of Lake Fork Creek, a 11.7-foot zone at the base of the Meade Peak member was found to contain 14.1 percent P_2O_5 (55, p. 32). The strike length of this outcrop is approximately 1 mile, and the beds dip about 35° S. About 8 miles west the formation crops out on the flanks of Rock Creek Valley. In the wide valley floor it is covered by alluvium, and on the crests of the ridges it is overlain by other Tertiary and Quarternary deposits. Total strike length of this outcrop is roughly 6 miles, with about 1.5 miles covered by alluvium. The dip is between 20° and 25° S, and the beds are displaced by two faults. The Geological Survey trenched and sampled a section of the Meade Peak member in Dry Canyon, exposing a 4.8-foot zone averaging 18.1 percent P_2O_5 (55, p. 30).

In the two areas of outcrop, a total of 300 acres of above-drainage level bed area is estimated for the Meade Peak member. Of this total, 35 acres is in the Mackentire Draw area and 265 acres is in the Rock Creek area. Assuming a 11.7-foot zone, the Mackentire Draw outcrop would contain 11 million tons of +14 percent P_2O_5 rock above drainage entry level. Because of the short outcrop, the below-drainage resources would be insignificant. Dry Canyon outcrop, using 4.8 feet of +18 percent P_2O_5 rock, has roughly 5.5 million tons above drainage level and 1.8 million tons for every 100 feet below.

Tertiary sediments cover an area a few miles to the west before the Park City crops out again in Wedge Hollow and continues in a discontinuous outcrop pattern around the western nose of the Uinta anticline. Total strike length of the exposures is about 35 miles. The Geological Survey excavated two trenches in this area; one in Wolf Creek on the south flank, and the other in Franson Canyon on the north flank of the anticline. The Wolf Creek trench exposed 6.1 feet of +18 percent P_2O_5 (55, p. 26), in two beds separated by a 1.5-foot carbonate rock bed. The Franson Canyon trench exposed two beds separated by about 2 feet of carbonate rock. The total phosphatic zone here was measured at 13.8 feet of +11 percent P_2O_5 rock (10, p. 21). On the basis of the above grade information the resources are estimated as follows:

	Million short tons
South flank (6.1 feet), +18 percent P_2O_5	198
North flank (13.8 feet), +11 percent P_2O_5	305

On the basis of available grade information these are latent resources and not applicable to the strict definition of this work. It is even doubtful that in the practical sense, the Dry Canyon section (4.8 feet, 18.1 percent P_2O_5) could be considered as containing a potential thickness of +3 feet in the +24 percent P_2O_5 class. These western Uinta deposits are primarily included to indicate the continuation of the large potential in the southeastern part of the range.

Flaming Gorge

In the eastern part of the north flank of the Uinta Mountains, the Meade Peak member extends nearly 30 miles in a north-dipping trend. Only about 10 miles in the eastern part of the area is considered in this report. This area of outcrop is bounded by Sheep Creek on the west, and on the east by the Flaming Gorge Reservoir (fig. 74). The Park City formation outcrop forms broad exposures on the slopes of the ridges south of Sheep Creek. Part of the deposit on the east, in fact, will be flooded when the reservoir level reaches its maximum height. Access to the area is through Manila, Utah, and several good gravel roads off Sheep Creek. The nearest rail facility is at Green River, Wyo., about 50 miles north. Almost all of the phosphate exposures lie within the boundaries of Ashley National Forest.

The dips of the Meade Peak member exposures range from about 8° to 35° N; the most gentle dips are on the eastern end. There is one comparatively wide exposure on the west side of the reservoir, however, that dips consistently at about 8°. At the western end, where the Park City formation crosses Sheep Creek the dip is about 20°; the majority of the attitudes are between 15° and 20°. Throughout practically the entire length of the area, the Meade Peak member either dips off the hill or just under the crest (fig. 75). The structure of the phosphate belt is simple except in the extreme eastern end where it is faulted off against the Uinta thrust zone.

The eastern end of this Meade Peak member outcrop was sampled by the Geological Survey in Horseshoe Canyon (12, pp. 22-24), where a little more than 6 feet of +24 percent P_2O_5 rock was found (table 53). Farther west, in Sols Canyon, the grade of the basal zone was found to decrease to about 6.6 feet of +14 percent P_2O_5 rock (12, p. 33). At Sheep Creek, the basal zone thins to about 2.8 feet of +25 percent P_2O_5 rock, and another 3.2-foot bed of +15 percent P_2O_5 occurs about 12 feet above this zone (63, pp. 24-25). Since this is an area of low dip and broad outcrops, the above-drainage level bed area is comparatively large. Using thicknesses and grades in the sections at Horseshoe Canyon and Sheep Creek, the above- and 100 feet below-drainage resources are as follows in millions of short tons:

Grade, percent P_2O_5	Above drainage entry	100 feet below
+24....................	83.9	3.2
+18....................	107.0	4.4
+10....................	389.7	16.0

The outcrop west of Sheep Creek Canyon was not considered since no +3-foot +18 percent P_2O_5 zone could be established.

Most of the area of exposure in this vicinity lies on leased or claimed land, but the potential is low because of the relatively great distance (±50 miles) from railroad facilities. It is not yet feasible to transport ±24-31 percent P_2O_5 rock by road, although it may be possible in the future to set up a beneficiation plant on or near the property. The eventual power source from the nearby Flaming Gorge Dam is an advantage in this respect.

Nearly all of this outcrop length is covered by phosphate leases or prospecting permits. A majority of the best occurrences are controlled by the Yuba Consolidated Industries Inc. (San Francisco). This company did a

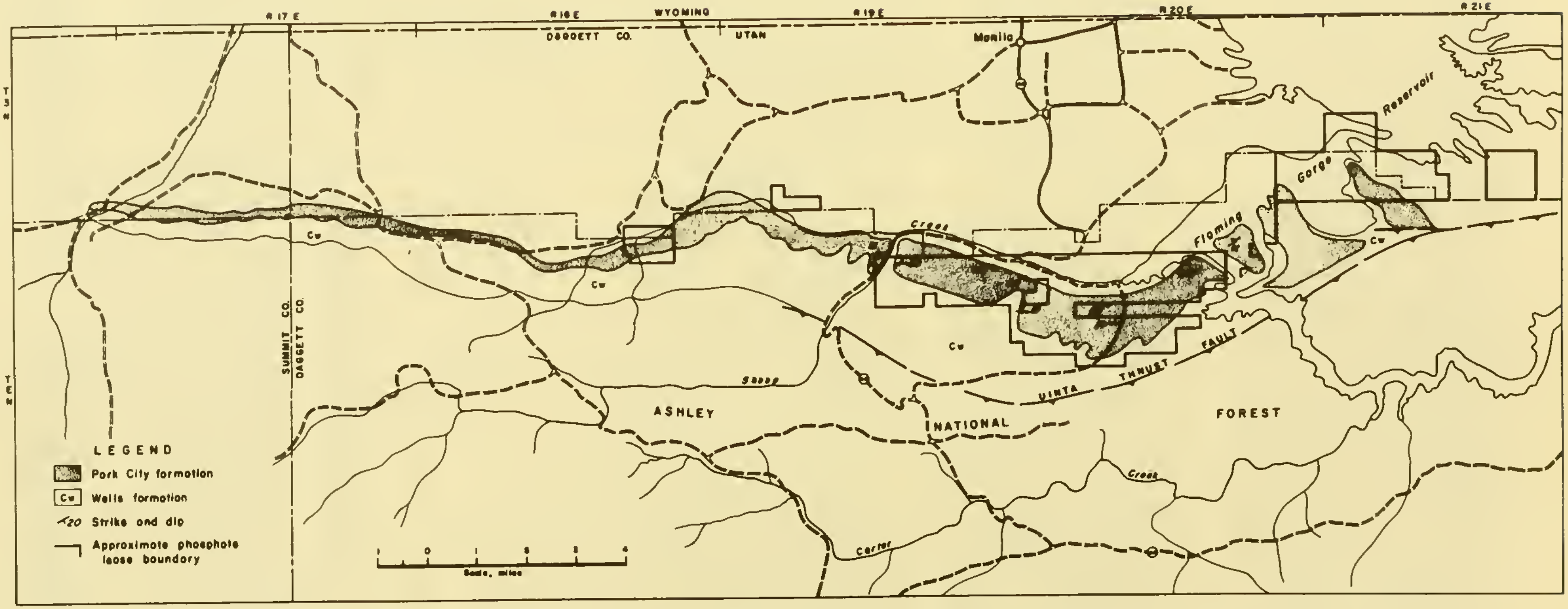

FIGURE 74. - Flaming Gorge. (Modified from Anderman, Hansen, Stokes.)

FIGURE 75. - Park City Formation Dipping North Into Sheep Creek Canyon.

considerable amount of exploration work in the area and a certain amount of beneficiation work on the phosphate rock. The studies so far have apparently not proven the economic feasibility of the area.

TABLE 53. - Meade Peak section in Horseshoe Canyon, Daggett County[1]

Lithology	Thickness, feet	Grade, percent P_2O_5
Carbonate rock and mudstone	7.7	6.2
Argillaceous phosphate rock, carbonate rock, and mudstone	5.5	12.1
Mudstone	7.2	8.8
Mudstone, phosphate rock, and carbonate rock	8.9	12.2
Phosphate rock	3.4	22.1
Mudstone and phosphate rock	3.4	9.2
Phosphate rock	6.1	24.1
Mudstone	0.5	7.9

[1] (12, pp. 22-24).

WASATCH RANGE DISTRICT

General

The Wasatch Range is a long, north-trending range extending 200 miles from Soda Springs, Idaho, to south of Provo, Utah. The area of phosphate occurrence, however, occurs only in the southern half of the range and is divided into northern, central, and southern sections in this report. The mountains vary in topography from very subdued, moderate hills to extremely rugged ridges with local relief to 2,000 feet. The structure and stratigraphy also vary considerably from simple to very complex character.

Until recently, the Wasatch Range contributed little to the overall resource outlook of Utah. However, in the 1963 field season, a relatively rich and previously unknown section was found in Dry Bread Hollow, about 22 miles east of Ogden (47). A summary of the phosphate in this section follows:

Acid-grade (+31 percent P_2O_5)................	2 feet
Furnace-grade (+24 percent P_2O_5)............	46.4 feet
Beneficiation-grade (+18 percent P_2O_5).......	81.6 feet

Release of the open file report describing this deposit has given rise to a considerable amount of exploration activity.

The northernmost Phosphoria outcrop in the Woodruff Creek area was of interest during the early development of the Wasatch area. This was one of the first deposits discovered, although interest soon turned to the more extensive deposits to the north. On the extreme southern end of the range, a small area of phosphate was developed and mined intermittently in the Little Diamond Creek area.

These three localities are the only occurrences of +18 percent P_2O_5 phosphate in beds greater than 3 feet in thickness. The southern extension of the Park City formation east of Nephi has not yet been examined by any agency or private organization.

Access to most of the explored outcrop areas in the Wasatch Range is comparatively easy. Several highways and railroads serve the area; the railroads converging at Salt Lake City and Ogden include Union Pacific, Denver and Rio Grande, Western Pacific, and Southern Pacific. The areas of exploration are generally accessible by gravel roads off the main highways.

Geology

The geology of the Wasatch Range is complex. In the northern and southern sections the stratigraphy is wholly sedimentary, but in the central area, igneous rocks play an important role in the structural pattern. The Meade Peak phosphate member is cut by igneous rocks in several places in the Park City, Utah, vicinity. All of the phosphate exposures in the Wasatch Range lie within the realm of influence of the Park City formation, which is exposed as a discontinuous belt from the southern end of the Wasatch Mountains to Woodruff Creek.

The Meade Peak member rests directly on the Grandeur member, and is comparatively thick in the Wasatch Range, although the phosphate content is low in most areas. It reaches its thickest point at Devils Slide (303 feet) where it is split by a tongue of the Franson member. At Dry Bread Hollow, a recent trench exposed a thickness between the Franson and Grandeur tongues of 469 feet (47); however, the basal 207 feet of this is, as yet, an unnamed phosphatic unit.

Southern Wasatch Range

The southern part of the Wasatch Range (fig. 76) contains about 25 miles of Park City formation outcrops, beginning on the ridge south of Spanish Fork Canyon and continuing intermittently to a short distance north of the Utah-Wasatch county line. The exposures are interrupted by faulting toward the southern end, but most of the breaks are caused by the overlapping sediments of the Upper Cretaceous Price River formation. All exposures on this trend are east dipping, except at the north end where the Park City swings into a north plunging syncline for a short distance.

The Meade Peak phosphate member has been trenched and sampled by the Geological Survey at four localities (12, p. 41). The southern trench located in a small, inactive mine on the ridge north of Little Diamond Creek exposed a 5.8-foot bed of +28 percent P_2O_5. It is not known how much rock was shipped from this pit, but it was operated intermittently in recent years. The Federal lease on this property (840 acres) is currently owned by John M. Uren of Salt Lake City.

A little farther north in Wanrhodes Canyon, another trench exposed a basal, 3.7-foot bed of +20 percent P_2O_5 (55, p. 47). In the other two trenches, one on the Right Fork of Hobble Creek and the other in Strawberry Valley (12, pp. 35-39), the phosphatic content was not localized except in negligible amounts. At Strawberry Valley, there are two +12 percent P_2O_5 zones totaling 7.3 feet and a 3.1-foot zone of +16 percent P_2O_5. At Hobble Creek there are no +3-foot zones of +10 percent P_2O_5 rock.

Phosphate resources of the Little Diamond Creek area have been estimated at 1.3 million tons of +25 percent P_2O_5 rock in a 5-foot bed taken to a depth of 2,500 feet (63, p. 41). This is calculated on a relatively short strike length of probably from 600 to 800 feet, which is the approximate length of the knob where the mine is located. Extending this zone to the nearest practical drainage entry point at Little Diamond Creek would give roughly 5 million tons above and 350,000 tons 100 feet below entry. In view of reports of inconsistent grade fluctuations in this area the earlier estimate may be more realistic. The mine is conveniently located a few miles from a railhead and transportation outlook is favorable. It appears that this particular deposit represents a good potential for a small amount of phosphate rock available by open pit methods. In view of the rapid decline in grade to the north and possibly to the south, it cannot yet be considered a large (several millions of tons) potential reserve area. Here again, the market for this type of rock would be limited, since it is not acid-grade, and the only processing plant

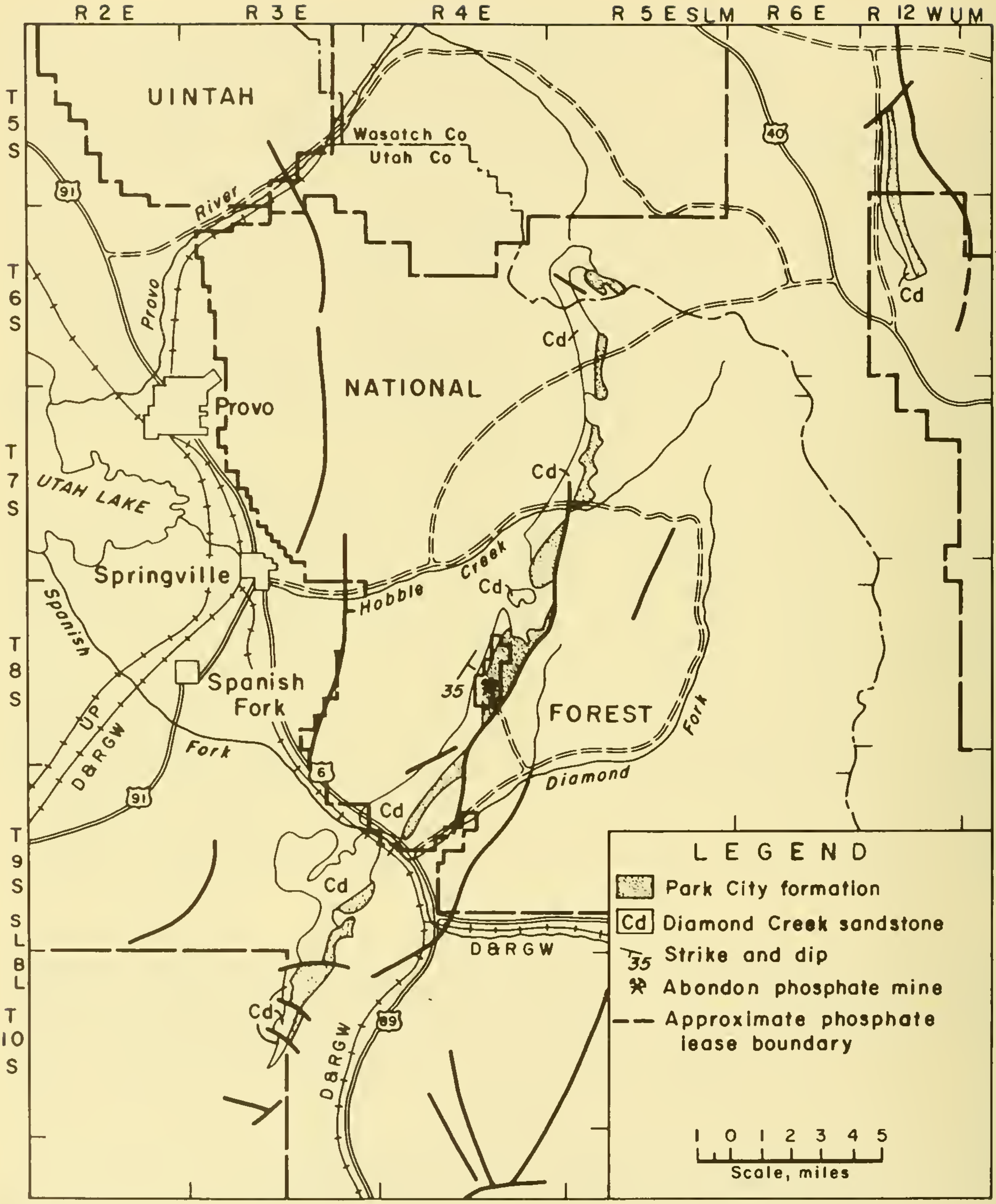

FIGURE 76. - Southern Wasatch Range (57). (Madified fram Baker and Stakes.)

in the Salt Lake City area is Western Fertilizer's wet process facility at Garfield. Development of the Little Diamond Creek deposit would involve a beneficiation process.

Central Wasatch Range

The central Wasatch Mountains (fig. 77) includes the general area east of Salt Lake City to the Provo River Valley and extends north to Huntington Creek. The topography is rugged but the area is accessible because it is within the Park City Mineral Belt and is close to population centers.

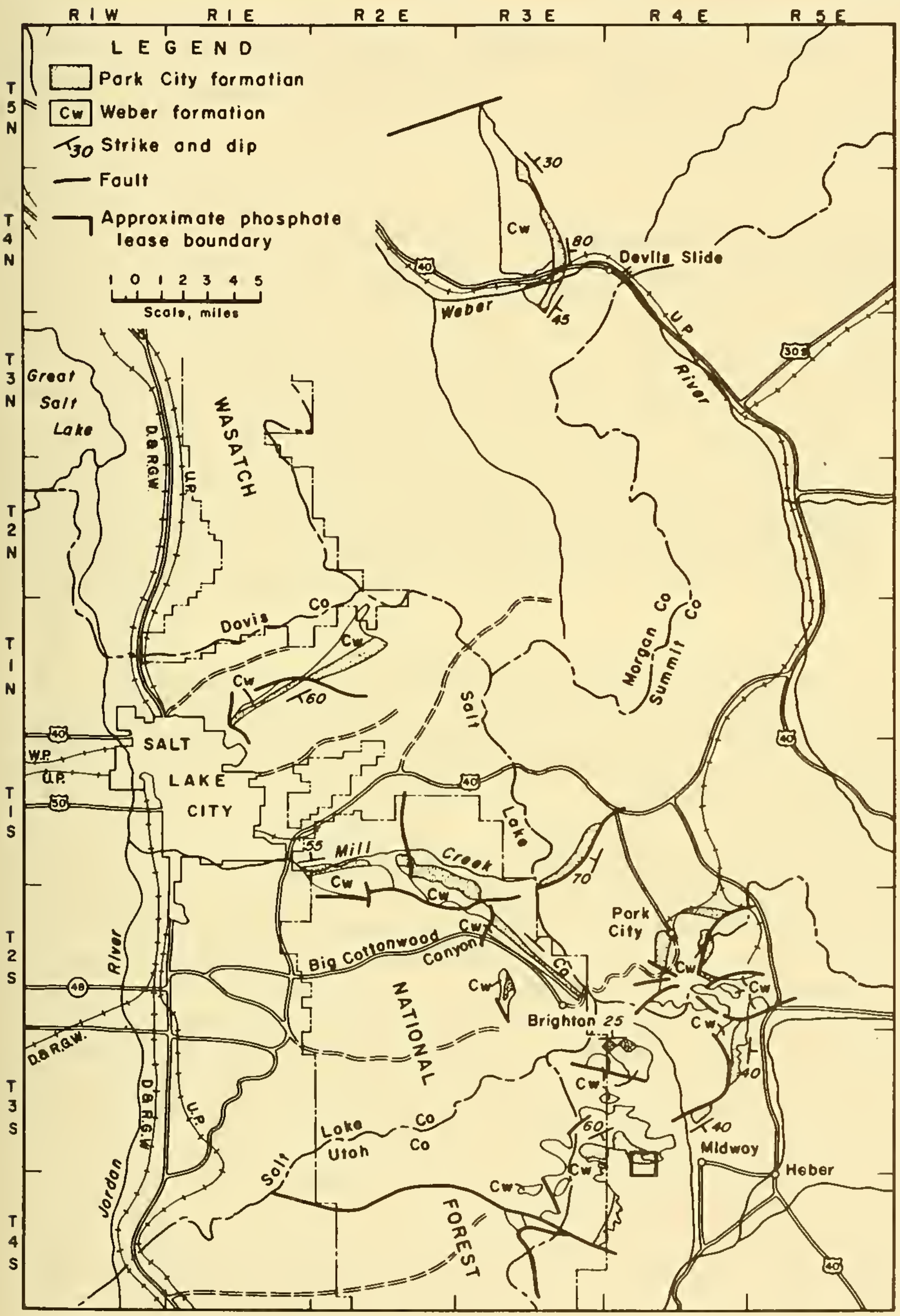

FIGURE 77. - Central Wasatch Range (40). (Modified from Baker, 1961, Geological Survey unpublished preliminary maps, Crittenden, Mullen, Stokes.)

The geology of the area is complex and the predominating feature is a central igneous mass that cuts through a mesozoic and Paleozoic sedimentary belt. The majority of the sediments on the immediate slopes of the Salt Lake Valley show an east-west strike typified by most of the valleys east of Salt Lake City. This is only local, and the structure changes abruptly with the numerous faults and with the influence of the igneous bodies.

The Park City formation is underlain by the Weber quartzite and follows its general structural pattern. It is a comparatively resistant formation and for some distance forms the north wall of Mill Creek Canyon. It is cut at several points by igneous rocks, and a good example of this occurs at Scotts Pass on the road between Brighton and Park City. The Triassic beds and the Park City and Weber formation, north of the road, are striking south into an igneous mass occurring south of the road.

The resources of the central Wasatch Mountains have been estimated as 8 million tons of 50 percent bone phosphate of lime (BPL) (+22 percent P_2O_5) lying entirely in the area north of Midway. No rock under 40 percent BPL (+18 percent P_2O_5) was considered (64, p. 21).

The longest, and nearly continuous, trend in the area is an outcrop extending from the mouth of Mill Creek to Scotts Pass in a wide arc, to where it is faulted out against the Cottonwood batholith; a strike distance of nearly 14 miles. This exposure is faulted off, displaced, and covered by later sediments at several places; dips are 30° to 60° to the north and northeast. Williams (63) cites a locality where Gale and Richards reported a 3-foot bed containing 32.6 percent P_2O_5 on Section Ridge in Big Cottonwood Canyon. He estimated 9 million tons of phosphate resources (63, p. 35). However, in a later survey, two trenches were excavated and sampled and the quantities of phosphate in this outcrop were found to be very lean; the phosphate was confined to several beds only a few inches thick and normally containing less than 15 percent P_2O_5 (64, pp. 15-16). While this outcrop is quite long and represents a considerable bed area, no resource estimates were made because of the low grade.

Another outcrop of the Park City formation extends about 4.5 miles in a northeast direction in the upper plate of a thrust that brings the Park City formation over Jurassic sediments. While this outcrop also contains a considerable amount of bed area, there is no information concerning grade or thickness of any possible phosphatic zones.

Near Midway and Park City, the Park City formation crops out for a total strike length of approximately 16 miles. In an earlier survey, northeast of Park City, one bed was sampled that analyzed +14 percent over a thickness of 5.9 feet. Another zone was sampled on the 1,300 level of the Silver King mine, southwest of town, and measured 10.7 feet of +13 percent P_2O_5 (64, pp. 18-19). The outcrop north of Midway contains a 3.5-foot zone of +26 percent P_2O_5 where sampled by Williams (63, p. 35). Using this bed as a basis, the area could contain about 7 million tons above drainage level; however, this is the only occurrence of this type in a considerable area, so it is more likely that the sample represents only a short outcrop length. The only grade information on the exposure west of town shows a 5.9-foot zone that analyzed +12 percent P_2O_5 (64, p. 20).

Another trend of the Park City formation begins near the Salt Lake City limits and extends about 7.5 miles in a northeasterly direction before it is covered by later Tertiary gravels (Almy conglomerate). The beds dip about 60° to 60° S and at the west end the formation dips off the hill on the north side of a dry gulch. The central part of the outcrop is accessible by a road up Red Butte Creek.

The outcrop was trenched and sampled near the eastern end by the Geological Survey (12, pp. 25-31). The phosphatic shale member was measured at 682 feet at that time. McKelvey later assigned 303 feet to the Meade Peak member, including a tongue of the Franson member (38, p. 22). There are several thin phosphatic zones in the section; the highest grade bed is 3 feet thick containing +26 percent P_2O_5. This zone occurs about 300 feet above the base and is the lowest phosphate bed in the section. The thickest phosphate zone is a 14-foot bed of +17 percent P_2O_5 (12, p. 26).

Based on the above grade information, the latent resources of the outcrop would be as follows:

Percent P_2O_5	Thickness, feet	Million short tons
+24..................	3	12.5
+18..................	4.7	18.1
+10..................	18.6	69.9

This outcrop is eroded and covered by a wide area of the Tertiary Almy formation before it crops out again in the Weber River Canyon near Devils Slide. There was a development operation started in this area some years ago; however, the section did not contain a rich enough phosphate zone to be of interest. The Geological Survey sampled the section (12, pp. 11-17) and found a total of 20 feet of +12 percent P_2O_5 rock occurring in four beds dipping 20° to 60° E.

Northern Wasatch Range

The northern Wasatch Mountains (fig. 78) contain three, widely scattered, small exposures of the Park City formation and Meade Peak member, all of which have probably the richest sections of phosphate enrichment in the Western field. This northern Wasatch region, however, is typically covered over great expanses by Tertiary sediments (Eocene Knight Conglomerates) and, as a result, the two northern outcrops are exposed in valleys with small above-drainage bed areas. The southern exposure occurs higher up on the valley wall but is still covered by Tertiary conglomerates and does not crop out for any great distance.

The southernmost exposure occurs as an east limb of a north-plunging syncline in Dry Bread Hollow, a north-trending valley off the South Fork of the Ogden River. The exposure is roughly 20 miles by paved and gravel roads and 2 miles by trail from the city of Ogden.

This phosphate occurrence was previously described by Blackwelder (7, pp. 545-551); however, at that time he was not able to determine thickness or grade of the phosphatic zones. In 1963 the section was trenched and sampled by the Geological Survey, and the following total phosphatic section was exposed:

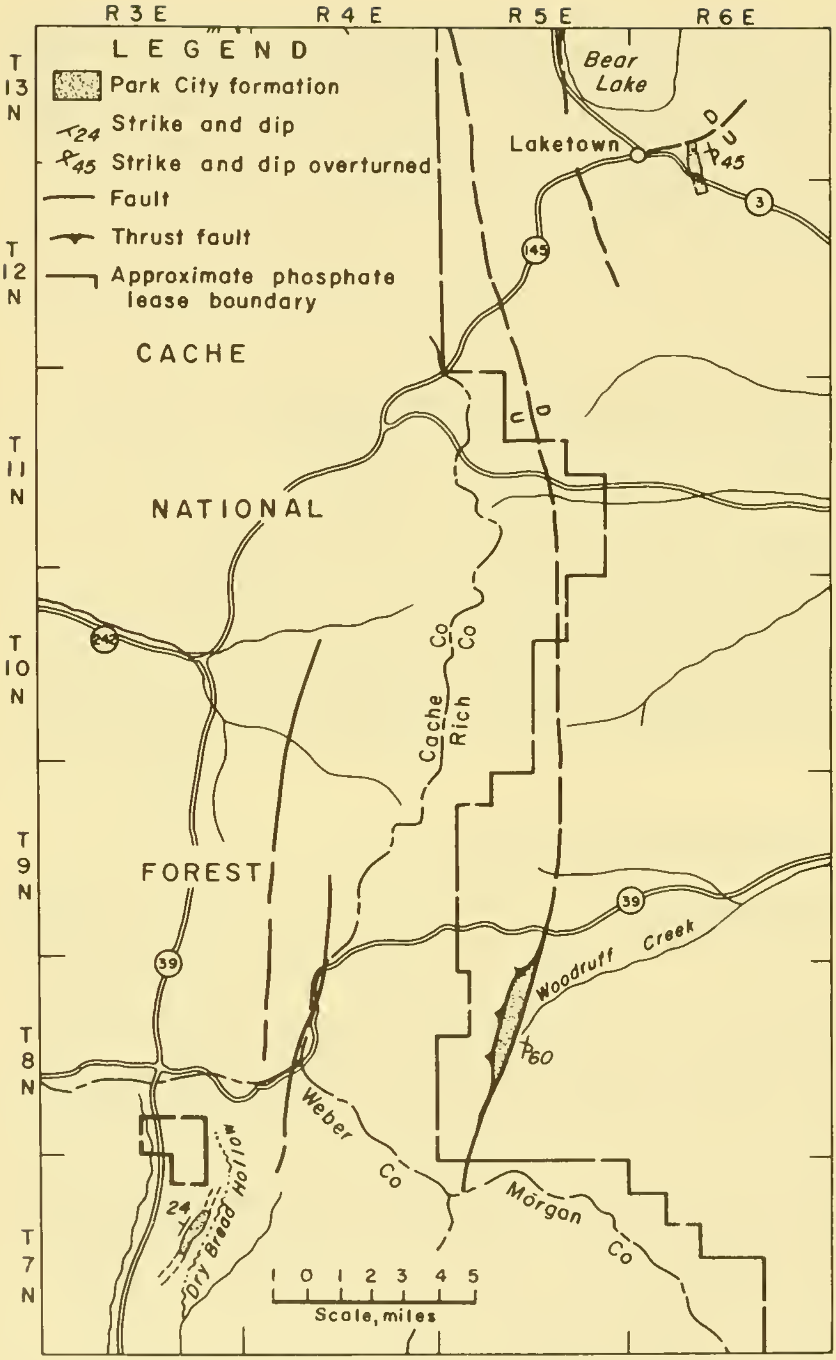

FIGURE 78. - Northern Wasatch Range. (Modified from Richardson, Schell and Stokes.)

	Feet
Percent P_2O_5:	
+31.............	2
+24.............	46.4
+18.............	81.6

The total +18 percent P_2O_5 resources estimated for a restricted part of this outcrop and taken to a depth of 2,000 feet were 45.2 million tons (47, p. 6).

The total thickness of the Park City formation was 932.9 feet with a small part of the formation eroded and covered by Tertiary sediments (47, p. 3). In all, eight rock units were recognized; six of these are formally known to be members of the Park City and Phosphoria formations. The following units were measured:

	Feet
Upper sandstone..	8.7
Ervay Carbonate member..........	60.0
Retort member....	33.9
Rex chert member.	276.1
Meade Peak.......	262.7
Unnamed..........	207.0
Grandeur.........	51.0
Total.........	932.9

Most of the phosphatic enrichment occurs in the Meade Peak member, but two significant zones occur near the base and top of the lower "unnamed" member. Bed thicknesses are: +24 percent P_2O_5 rock, 36.5 feet; +18 percent P_2O_5 rock, 49.6 feet; and +10 percent P_2O_5 rock, 69.0 feet.

In this work a simple geometric model of 5,000 feet (approximate length of outcrop) by the various bed thicknesses by 100 feet of down dip advancement is used. The resource figure for each 100 feet down dip is:

	Million short tons
Percent P_2O_5:	
+24	1.52
+18	1.91
+10	2.59

Taking an arbitrary figure of 300 feet, or the approximate height above the level of Dry Bread Hollow at which the shales crop out, the down dip (26°) advancement would be roughly 700 feet. Resources to this point in the +24 percent, +18 percent, and +10 percent P_2O_5 category would be 10.6, 13.4, and 18.1 million tons, respectively.

There has been considerable activity in the area in an attempt to gain mineral ownership in the form of prospecting permits and leases. As a result, there should be a considerable amount of information accumulated by private parties concerning the present economic significance of the area.

About 13 miles northeast of Dry Bread Hollow, the Park City formation crops out for about 3.5 miles across the Woodruff and Sugarpine Creek drainages. This was one of the first areas discovered in the early development of the Western phosphate field and was first reported on by Blackwelder (7, pp. 526-529). There are still remnants of the earlier exploration in the form of prospect pits, trenches, etc.

Since this area was one of the first to be discovered in the Western field, the initial interest was high. Several claims were established by private individuals and companies, and a small amount of exploration was undertaken. As better areas became known, interest in the Woodruff Creek deposit decreased and, at the present time, there appears to be no one actively interested in the area. The Geological Survey sampled and measured the upper and lower phosphatic zones in 1953 (58, p. 14).

The geology of the Woodruff Creek area is characterized by faulting, overturned beds and a Tertiary erosion surface on upturned Mesozoic and Paleozoic sediments. The phosphatic shales and adjacent strata occur on the overturned west limb of a syncline that strikes nearly north-south and are exposed in the deep canyons of Sugarpine and Woodruff Creeks. The east limb of the syncline does not crop out. The phosphatic shales are bounded by faults on both sides and are in contact with the Cambrian Brigham quartzite on the west and the Jurassic Nugget sandstone on the east. Both of these horizons are overturned.

To the west, the Brigham quartzite is overturned and occurs in an overriding thrust block. On the intervalley areas, the Paleozoic and Mesozoic rocks are covered by the flat-lying Tertiary Wasatch formation on a relatively extensive Tertiary erosion plane. This erosion surface is the most obvious geologic feature of the area.

The phosphatic section in this area is comparatively thick; this is mainly attributed to the well-known pre-Wasatch erosion and enrichment of the beds near the surface. The Geological Survey measured and sampled a total of 24.1 feet of +24 percent P_2O_5 rock which is dipping 55° and was overturned to the west (58, p. 30).

This section appears rich; however, the available resources are comparatively small since the Meade Peak member only crops out in the valleys. It is covered on the hills; vertical relief is quite small, and there are almost certain to be faulting complications at depth. There is the possibility that this grade may be superficial and not exist for any depth greater than 25 to 50 feet below the surface. The above-drainage resources are comparatively small and would not add appreciably to the overall resource figure. On the basis of the 3-1/2 miles of strike length, this area would contain acid-grade and furnace-grade rock in the amount of 1.9 and 3.7 million tons, respectively, for every vertical 100 feet of depth.

A limiting factor in this area is that the deposit is located 40 to 50 miles from the nearest railhead either at Leefe or Evanston, Wyo. If the rock characteristics were such that the mine-run, high-grade zone could be processed by grinding and washing, then an operation might be possible if enough high-grade ore could be developed.

About 25 miles north of Woodruff Creek the Park City formation crops out in an overturned section 1.5 miles east of Laketown. This area is similar to the Woodruff Creek area in several ways: the structure is overturned (50° to 60° to the west), the wide expanse of Tertiary sediments cover the area and the Park City crops out only in the topographic lows and, finally, the phosphatic section is comparatively rich. The area was first mapped by Blackwelder and the Park City formation was assumed to be lying in an overturned anticline, with another outcrop on the west limb about one-half mile west (7, pp. 522-526). It was later found that the western outcrop was a phosphatic zone in the Mississippian Brazer formation (10).

The Meade Peak member was trenched and sampled at this locality, and 90 feet was exposed with zones of phosphate enrichment at the base and the top; the entire section averages +14 percent P_2O_5 (12, pp. 5-6). The basal zone is a series of thin beds totaling a little over 14 feet of +20 percent P_2O_5 rock. This zone can be separated into smaller units of higher and lower grade material. There have been attempts made at developing this deposit on a small scale (fig. 79), but the amount of production, if any, is not known.

The upper phosphate zone, a little richer, totals 23 feet of +24 percent P_2O_5 rock, including a fairly definite 9.5-foot bed of +31 percent P_2O_5 rock. Considering both phosphate zones and selecting the boundaries to delineate beds of all grades, the total thicknesses would be: 9.5 feet of acid-grade, 32.1 feet of furnace-grade, 65.4 feet of beneficiation-grade, and 90.4 feet (the entire section) of low-grade (+14 percent P_2O_5) rock.

The topographic relief on the Meade Peak member is low and no significant tonnages of above-drainage level resources occur. The outcrop is at an

FIGURE 79. - Phosphate Pit, Laketown, Rich County.

elevation of about 7,000 feet, and the resources for each 100 feet below drainage level in the respective grades would be:

	Million short tons
Acid......................	0.6
Furnace...................	1.9
Beneficiation.............	3.5
Low.......................	4.8

This area represents a relatively high potential. Assuming that the rich zones exist for 50 feet below the surface and assuming the length of outcrop at 6,000 feet (allowing 1,000 feet for canyon and road right-of-way loss), the possible open pit resources would be:

	Short tons
Acid......................	250,000
Furnace...................	800,000
Beneficiation.............	1,510,000

RESOURCE AND POTENTIAL SUMMARY

There is estimated to be more than 700 million and 2.5 billion tons of +10 percent P_2O_5 phosphate rock above drainage entry level in Wyoming and Utah, respectively. This is estimated on rock occuring in +3-foot beds. In addition to these tonnages, there are also estimated to be, roughly, 2.8 billion tons of +10 percent P_2O_5 latent phosphate rock in Wyoming. The latent classification is determined arbitrarily on the basis of grade and accessibility; however, there are a number of other factors that may contribute to the eventual development of some of these deposits.

At the present time, the economic potential is governed by the same factors that affect the rest of the field, since the market area is mainly the Western States. This may change to some extent with the possible future development of the southeastern Wind River Range phosphate deposit and of the fertilizer complex planned for the Vernal field. The Wind River Range rock could conceivably be shipped to the neighboring States on the east cheaper than to the Pacific market area. The production of a fertilizer product at Vernal would essentially open up markets either to the east or west for that area.

At present, the Wyoming and Utah phosphate industry includes two open pit mines, one underground mine, and two beneficiation plants. All of the Vernal plant concentrate and part of the Leefe plant concentrate are shipped to the Western Phosphates Inc. plant at Garfield. This facility was constructed in 1953 and coincided with the development of deposits in the Crawford Mountains. Production of phosphate fertilizer products has been steadily increased to an approximate yearly output of 100,000 tons of concentrated superphosphate, 50,000 tons (P_2O_5) of phosphoric acid, and 10,000 long tons (P_2O_5) of diammonium phosphate. The plant is owned jointly by Stauffer Chemical Co., Kennecott Co., and Garfield Chemical Co. The sulfur requirements are supplied as a byproduct from the nearby Garfield copper smelter.

Aside from the presently producing areas, the deposits that appear most favorably situated for development are in the southeastern Wind River Range and the Sublette Range. Both localities are conveniently located with respect to transportation.

The Snake River Range (Idaho) and the Salt River Range (Wyoming) have yet to be actively explored. The Snake River Range is closer to transportation with a railroad spur ending at Victor, only a few miles from the nearest outcrops. The Salt River Range is more remote, the nearest railhead being about 40 miles distant at Border, Wyo. Both areas contain substantial resources, mainly in the beneficiation-grade (+18 percent P_2O_5), but commercial extraction in most cases would involve upgrading.

A small part of the Tump Range, near Cokeville, and the southern end of Absaroka Ridge north of Kemmerer, may have some future phosphate potential. The Tump Range has a fairly good mining section in a small outcrop length about 12 to 15 miles from the railhead at Cokeville. North of the South Mountain mine on southern Absaroka Ridge, the phosphate grade increases substantially (+6 feet of ±30 percent P_2O_5 rock) so that there may be a significant amount of resources developed in the future. The road haul in this area would be about 15 to 20 miles.

In Utah, a few areas could contribute small amounts of potential phosphate resources. The most attractive site appears to be the Little Diamond Creek outcrop that has been mined previously. This exposure contains a substantial volume of minable ore above drainage level. Farther to the north, the Laketown and Woodruff Creek areas contain a small amount of higher grade material. The Laketown deposit is well located with respect to processing facilities (Leefe), but there is very little above-drainage minable ore. The Woodruff Creek outcrop Woodruff Creek outcrop contains a thick section, but the structural complexities here limit any prediction as to future potential.

The Dry Bread Hollow area east of Ogden will, undoubtedly, be the object of some intensive exploration activity in the near future. It is located about 22 miles from the railroad at Ogden and contains a thick section of +24 and +18 percent P_2O_5 rock. One section in the Meade Peak contains nearly 40 feet at about 24 percent P_2O_5.

In the vicinity of Flaming Gorge, considerable resources occur above drainage level in rock near the furnace-beneficiation grade boundary. The main detriment here is the distance to rail transportation, roughly 60 miles to Green River, Wyo. The nearby availability of low cost power from the Flaming Gorge Dam could conceivably improve the potential outlook of this vicinity.

In the final analysis, the future disposition of the undeveloped phosphate deposits in Wyoming and Utah remains to be determined by a number of factors. Development in the richer part of the Idaho field is expanding rapidly where there are vast open pit resources available. It is felt that the expansion of the Idaho field will compensate for the increasing phosphate market for some time to come, so that the undeveloped Wyoming and Utah deposits, for the most part, must wait for future markets or depletion of the more easily accessible Idaho deposits.

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